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DEVELOPMENT OF FINE GRASPING BEHAVIOURS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Development of Fine Grasping Behaviours" submitted by John A. Hay in partial fulfilment of the requirements for the degree of Master of Arts.

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CHAPTER I

INTRODUCTION

The Problem, its Nature and Significance

The study of the development of motor behaviours has been a significant area of research throughout the last century. Whether the concern has been with basic human motor behaviours such as locomotion or prehension or with culturally-normative motor skills such as catching or throwing, the questions of how and when motor development occurs have evoked a large body of research. The large majority of early studies focussed on the developmental schedule or sequences for the acquisition of motor behaviours. In addition they often provided detailed descriptions of the immature forms of those behaviours as they progressed toward some mature form of functioning (Gesell and Amatruda, 1947; Shirley, 1931). The results of this research are the well known developmental scales wherein the development of any number of motor patterns are described in terms of stages, each stage being achieved within some typical age range by the non-handicapped child. While such scales perform an admirable purpose in allowing clinicians to study the development of any particular child in relation to the norm, they provide little information as to the possible existence of more subtle but significant developmental trends within the achievement of mature motor functioning. This thesis will concern itself with the existence of such developmental trends. Children aged 3, 4 and 5 and an adult group will be tested on a grasping task which will facilitate the precise measurement of grasping forc-

es, thus enabling the study and comparison of one aspect of prehensive performance. The study is cross-sectional in design and developmental in nature.

The Research Problem and Questions

Little data is available concerning improvements in the quality of performance within the development and production of genotypic motor skills such as prehension. This difficulty was perhaps best stated by Shirley (1963) who recognized that "there is a great difference between ability to do and excelling in the doing of motor acts. The motor sequence takes into account only the former .. it is not concerned with the proficiency with which they performed each act." Using the development of prehension to illustrate, it has been thought that by the age of 12 months children are capable of virtually adult level prehensive skill as they have now achieved the adult form of prehension, the "pincer grasp" (Twitchell, 1965). Halverson (1932, p. 61) perhaps the most prolific of the early researchers dealing with prehension stated that "in accuracy of reaching and in precision of grasping, infants of 60 weeks rank almost on equal terms with adults in prehension of objects of regular form and of average size." Whether or not this is indeed the case is open to question as Halverson had no objective means with which to measure the "precision of grasping" of the infants he studied. The first question with which this study will attempt to deal then comes into view: Is there or is there not an achievement of adult level precision of grasping in young children? Precision of grasping will be measured in terms of the

force of grasp displayed in normal prehension. The quality of grasping will be measured by the appropriateness of the force applied, with the standard of quality established by the adult group.

A second perspective from which to view this problem is that of developmental motor learning. The concern here is with the actual process of motor development and if this process can be better understood by examining a basic motor skill such as prehension. Questions of this nature have typically dealt with the acquisition of culturally-normative motor skills; and as a result, little information is available as to the development of skills such as prehension apart from the previously mentioned developmental scales. As Connolly (1972) notes "Outside the context of developmental diagnosis by the establishment of developmental norms, little work has been done on the ontogeny of hand usage in man." This is not surprising as observational scales of motor development only provide information on the age-appropriateness of a particular child's behaviour. Simply observing motor behaviour does not provide sufficient information to trace the development of qualities within that behaviour. Perhaps more importantly the great developmental studies preceded the recent surge of interest in the processes of skill acquisition and motor development. Only within the last two decades have researchers begun attempts to view motor development in the light of the knowledge acquired regarding the acquisition of motor skills. The works of Bower (1977), Connolly (1979) and Wade (1975) are examples of recent efforts in this direction.

A further point of conflict in combining these two aspects of study is that the earlier research dealing with developmental patterns was decidedly maturational in perspective while more recent research concerned with skill acquisition is basically environmentalist in nature. The former was dedicated to chronicling the genetic unfolding of predetermined sequences, the latter concerned with the effects of practise, attention, memory and psychosocial variables. Recently, Lerner (1976) has provided an interactionist perspective that integrates these two positions. This compromise position allows both bodies of knowledge to be considered in the context of developmental studies. We are then led to the second question considered by this study: Are there variations in the preciseness of grasping that might indicate developmental differences between children and adults apart from the achievement of form? That is, is the quality of grasping between children and adults sufficiently different to indicate developmental differences in the quality of motor control? The indice of quality examined in this study will be that of grasping force.

The two questions may then be posed side by side. Are there differences in the quality of grasping between children at different age groups and adults; and if such differences do indeed exist can they be viewed as indicators of developmental trends in the production and control of motor skills?

These questions cannot be adequately addressed outside of some theoretical framework. Unfortunately at this time, no satisfactory theories of human motor development are established

to provide that framework. For that reason the perspective from which this thesis is written within will be outlined. This should not be construed as an attempt to create a universally acceptable theory of motor development. Rather it is an attempt to provide a context sufficient for the needs of this inquiry.

Theoretical Perspective - Developmental Human Motor Performance

Questions concerning beginnings are among the most difficult with which scientific endeavors must contend. The study of human motor development is no different. Although exhaustively documented accounts of the sequence of motor development exist (Dewey, 1935) relatively scant attention has been paid to the processes which drive and initiate that development (Wade, 1974). The result has been a situation wherein a large body of observational data floats within a theoretical void. In order to rectify this circumstance, it is evident that attention must be directed toward gaining an understanding of the determinants of motor development (Scarr-Salapetek, 1976). Traditionally questions of this nature have been approached from either of two firmly entrenched perspectives, maturational or environmental (Spalding, 1875). As previously noted more recent theoretical positions allow development to be viewed as the product of a dynamic interaction between an individual's environment and genetic inheritance. Within this theoretical context a more satisfactory model of human motor development can be constructed, and it is within this context that this thesis is written.

The human infant is born possessing two significant endowments, both of which are dependent upon a suitable environment for their fulfillment, the achievement of volitional movement.

These endowments, reflex movements and the drive to reduce uncertainty will be discussed in turn.

On one hand, the child is born with a set of reflex motor behaviours which could be viewed as precursors of movements essential to survival (Bruner, 1973; McGraw, 1932; Twitchell, 1975a). The human infant "comes into the world with a complex set of reflexive units in virtually every area of his physiological constitution" (Zelazo, 1976a). Referred to as the "hereditary equipment" of the child by Piaget (1963) these behaviours are meaningless outside of an appropriate environmental situation and of no consequence without subsequent usage. Connolly (1972), for example, has noted that the development of prehension "is based upon the reflex substrates which develop and change during the first months of life." Twitchell (1975b) observed that "each stage in the evolution of the automatic grasping reactions is associated with an increasingly complex form of volitional grasping." McDonnel (1979) however has observed that it is an oversimplification to state that voluntary behaviours, particularly reaching and grasping, are simple mature, cortically controlled expressions of primitive reflexes. It should be made quite clear that the importance of reflex movements is that they provide an initial basis for the development of movement skills which are both genotypic and culturally requisite. The actual reflex should not be viewed as a movement requiring only intention to become an established voluntary behaviour. Indeed the evolutionary origins of the grasping reflex for example, perhaps more properly referred to as the grasping-hanging reflex, bear little resemblance to the motor

behaviours to which they are now adapted (Langworthy, 1932). While possibly once necessary for the continuing physical survival of the newborn (as the reflex allowed the mother to be grasped for transport, feeding and protection) the same reflex possibly now provides the initial movement experiences which assist in the development of voluntary prehensive behaviours which typify the normally functioning, mature human. To create an analogy, reflexes should not be viewed as complete sets of clothing waiting only to be worn but rather as bolts of cloth from which appropriate garments can be fashioned. While perhaps overextending the analogy it is evident that a great deal of time and practice will be necessary before perfectly fitting apparel can be produced.

On the other hand it appears that the normally functioning human infant is born possessing both the drive and the capacity to solve problems, or, worded differently, to reduce uncertainty or conflict within his environment (Lipsitt, 1969). This then is the child's second endowment. An initial drive to solve problems is evident in Papousek's (1969) work where he observed the apparent pleasure and satisfaction derived from problem-solving among infants. He notes that "it appeared as if some motivation other than hunger was involved- some demand to respond correctly or to solve a problem." Haith (1973) argues as well that "cognitive achievement is pleasurable" for the infant. Hunt (1969) suggests that there is "a system of motivation inherent in information processing and action." Flavell (1977) refers to this drive as a "'natural bent' ... to make use of the cognitive instruments that the species evolution and

individual's development have provided." Nunnally (1972) suggests that information conflict, or simply a problem "triggers a tropism, the goal which is the resolution of the information conflict by one method as well." Berlyne (1966) suggests that "conflicting elements or requirements often characterize the 'problems' that start us off inquiring or experimenting or thinking." For example, Kagan (1970) comments that "the infant is predisposed to attend to events that possess a high rate of change in their physical characteristics. Stimuli that possess light-dark contrast are most likely to attract and hold a newborn's attention." Perhaps pertinent as well are theories of play which describe play as the exploration, investigation and manipulation of the environment, which in turn produces arousing interactions at a pleasurable level (Ellis, 1971). From Ellis' perspective play is basically a form through which to produce uncertainty within the environment, the resolution of which is pleasurable. As H.F. Judson (1980) has stated, "at the beginning is curiosity ... the joy of figuring it out... The birthright of every child."

These then are two major endowments given to the child and upon examination they appear to be significant factors in the child's autoapprenticeship in motor development, albeit dependent largely on the supportive limits of the child's environment. It would seem reasonable to assume that environmental situations which allow the exercise of these capacities will facilitate the development of instrumental motor behaviours. Recent research by Zelazo (1972) would seem to support this as-

sumption. Zelazo reports that the active exercising of placing and primary walking reflexes among infants led to both a greater quantity and quality of walking-like responses and most significantly to a substantially accelerated onset of walking. In essence, practice of a reflex precursor to volitional behaviour led to the earlier onset of voluntary control of that behaviour. Zelazo notes that "walking movements produce spatial, visual and kinaesthetic changes in the infant's world" and that "these accompanying sensory changes may serve as the inherent reward that reinforces walking." The increased quality of the movement during exercise is evidence of the child's application of volitional control to a previously reflexive response, even though physically unable to engage in the actual movement unassisted. A possibly relevant finding is reported by Freedman (1975) where he notes that a lack of lower limb reflexes and generally poor muscle tone among Navajo infants corresponded with a delayed onset of walking as compared with Caucasian children. Of interest as well is a study by White (1963) in which he reports that a deprived environmental situation (in terms of restricted motor activity) led to a marked delay in the onset of voluntary reaching and grasping. While the evidence is not conclusive it would appear that some degree of active exercising of reflex percursors to species typical motor behaviour is essential for the normal development of voluntary motor control.

What is being expressed behaviourally through either the acceleration or delay of development in relation to the environmental situation is the concept of the norm or range of reaction.

Lerner (1976, p. 65) describes this concept as follows:

> "our genetic inheritance represents a range of potential outcomes, and the developmental outcome that eventually manifests itself will occur due to the interaction of the environment within this range of genetic potential."

In other words while we have genetically determined upper and lower limits, the actual behavioural outcome of development depends upon the interaction of the genotype and the environment within which development occurs. This would appear to be a satisfactory framework from which to view the findings of Freedman, White and Zelazo. The genetic potential expressed both in the production of reflex movement and as the drive to reduce uncertainty, interact with more or less favorable environments to produce the more or less optimal development of voluntary motor behaviour.

The development of volitional behaviour within this theoretical framework results largely as a consequence of the dynamic and interdependent interactions of two genetic endowments which gain expression through an appropriate environment. The relative strengths of these endowments and the real-life state of the environment will serve to canalize the development of motor behaviour (Waddington, 1957). Reflex movements provide a wide gamut of potential information input to the child. Some of the consequences of those movements will be pleasant (or unpleasant) and the child is then faced with the problem of replicating (or avoiding) that sensory state through a reproduction of the reflex movement. An alternate but not opposing expression of this sequence is that the reflex movements result in a great deal of potential information or uncertainty (Gibson, 1967),

and that the child is spurred to reduce that uncertainty, through the voluntary replication and control of that movement. In either case a gradual progression toward volitional control would be expected due to practice motivated by the drive to reduce or resolve uncertainty.

Once volitional control of the motor behaviour has been established the progression would then follow some sequential path to the achievement of the adult level of that behaviour as dictated by the culture of the individual. In terms of grasping this development would be from the undifferentiated response of the grasp reflex to the precise, predictive grasp of the adult. This progression would not only be one of the achievement of adult form but of the attainment of adult quality. While these two aspects have been linked in the past, there is little data to support this notion at present. Within this theoretical framework such a progression in terms of quality of skill as well as form of skill would be expected. The key point is that it is the attainment of some level of skill within any given form of that movement which will allow the progression to some more advanced skill form, for example from palmar grasp to pincer grasp. Keogh (1977) makes a similar suggestion when he states that some critical level of movement consistency (reliable and appropriate movement skills) probably must be achieved before movement constancy (flexible movement responses to novel demands) can develop.

As the infant learns to move intentionally the solution of those relatively simple problems within the environment that

initially stimulated learning will be more readily achieved. However, it should be apparent that this achievement will allow an entirely new series of more difficult problems to be recognized, problems with which the child's present state of motor control is not capable of adequately dealing. The entire process would then begin again, but at a higher level of difficulty, requiring the development of a higher form of the movement, or of more skilled level of some already achieved form. The expectation then would be a sequential development of voluntary motor control, each segment of the series being progressively more capable of responding to the higher cognitive demands of the child. Such sequential development has been reported in the achievement of volitional prehension for example, by Castner (1933), Halverson (1931) and White, Castle and Held (1964).

This notion of sequentially more advanced motor development in response to the need to reduce uncertainty has strong similarities with the Piagetian concept of intrinsically motivated circular reactions during the sensorimotor period (Brainerd, 1978). Circular reactions are defined as any movement sequence "that tends to be repeated because the actions produce forms of stimulation that lead to the repetition of the actions" (Brainerd, 1978, p. 50). Circular reactions are thought to occur when the child is presented with a moderately familiar stimulus, yet not as familiar as to be uninteresting or so unfamiliar as to be incomprehensible.

This progression then is, to a large extent, dependent on

the increased quality or skillful application of each proceeding step in the motor sequence. Bruner (1973) suggests that such well-timed, sequenced and modulated behaviour might free "available information processing capacity for further use in task analysis." Consequently, additional information will be available to the child concerning his environmental state, as he will be more able to attend to the object or result of interest (Kopp, 1974A). Thus, as the individual becomes more expert within some stage of motoric development the child will be able to process additional information about both the movements and their consequences rather than simply attending to the production of the actual desired movement. This additional information processing capacity could conceivably be applied toward both the recognition and the attempted motoric solutions of problems beyond the child's present behavioural repertoire (Hogan, 1975). In such a manner development would proceed. Within this limited capacity model of information processing it is evident that the more attention a child is able to focus on the consequences of the action rather than to the actual production of that action, the more potential information will be available to that child for learning.

While there are obvious beneficial spinoffs in terms of cognitive development from skillful motor manipulations, it should be stressed that for the infant the major benefit is that skilled performance of one movement form facilitates the development of performance of a more advanced form. The amount of channel capacity or attention required to perform those motor

acts basic to normal functioning - postural, prehensive, locomotive - at a skill level demanded of by society, will eventually be effectively minimized. In the adult, these behaviours probably become automated to the point where they require little or no conscious attention in normal use, thereby freeing attention for use in meeting other demands (Sage, 1977). These "automatic" behaviours are probably indicative of the establishment of cognitive rules which govern their usage (Bower, 1974), rules which have been developed from infancy by the recognition and reduction of uncertainty. Only when the sensory consequences of those movements conflict with the expected outcomes anticipated from past experience will conscious attention to the movement be required. This conclusion is congruent with expectations derived from Schmidt's (1975) schema theory of motor learning.

Schmidt (1975, 1978) suggests that movements will become increasingly precise as the number and variety of previously attempted, similar movements is increased. This increase in precision will be due to the greater development of two separate schemas, recall and recognition. The recall schema allows the performer to determine or anticipate an appropriate response based on information stored from past similar experiences. The recognition schema allows greater precision and error correction as it generates an anticipated set of sensory consequences based on prior experience. The more developed each schema the more accurate will be the initial response and the more precise will be subsequent corrections. In other words, varied practise at

some skill, for example prehension, will facilitate skilled motor behaviour when performing novel movements which incorporate that skill. Bower (1974) makes a similar suggestion when discussing the development of the differentiation of motor behaviour, particularly in regard to grasping.

Schmidt's concept of a motor schema then can be used to observe the development of skilled movement within some developmental form of the skill itself. In essence it creates a very congruent completion of a developmental spiral that concludes with the adult level of skilled behaviour of some species normative motor behaviour.

Summary

This thesis then will attempt to explore the possibility of continued development within prehension past the achievement of the pincer grasp. This development will be studied specifically in terms of the force of grasp which will be considered a prime measure of the quality of prehension. The possible development of more precise grasping will be discussed in terms of developmental human information processing theory as outlined in the theoretical perspective of this thesis.

Hypotheses

Hypotheses for this thesis are as follows:

1. that the temporal organization or timing of the grasp response in terms of force application will be similar for all age groups tested.
2. that more skilled performance, measured by reduced grasping forces will be evident among the older test groups.

3. that the older subjects will exhibit greater accuracy in predicting the required grasping forces following the initial trial.

Assumptions

1. It is assumed that the results of the samples tested reflect the populations which they were chosen to represent.
2. It is assumed that no hidden neurological problems were present in the subjects which may have influenced their motor behaviour.
3. It is assumed that the test situation measured as normal a behaviour in as normal a situation as possible and that the results accurately reflect each subject's normal level of functioning.
4. It is assumed that successful completion of the task reflected an accurate understanding of the task demands.
5. It is assumed that by the age of 20 years that adult-quality prehension has been fully achieved.
6. It is assumed that increasing age will correlate with an increased amount and variety of grasping experiences.

Delimitations

Due to the availability and selection of subjects, the use of volunteer subjects and the cross-sectional design employed, the following delimitations must be applied to this study.

1. The results can only be strictly applied to caucasian males of middle class socioeconomic backgrounds.
2. The use of volunteers from an educational gymnastic program may bias the results in favour of a more skilled than normal performance.

Limitations

1. Due to a consistent failure by a significant number of the younger subjects to grasp the smaller of the two test objects at its centre, results from this piece of equipment are not included. Grasping the test object near either of its ends led to distorted readings which were not admissable data. (See Appendix A)
2. Intervals between test trials could only approximate the desired times. Particularly with the younger children any number of factors led to inevitable distractions. It was felt that a relaxed and co-operative subject was of more importance than any conclusions a rigid adherence to a timing sequence might have allowed.

CHAPTER II

REVIEW OF LITERATURE

Grasping behaviours have long been a major area of interest to developmental psychologists. It is perhaps due to the uniqueness of the hand as a behavioural expression of the intelligence of the human species that such a strong concern has been maintained. From 1833 when Bell referred to the hand as "the ready instrument of the mind" the hand's capacity to functionally demonstrate the intelligence that controls it has fascinated science. Not surprisingly a great deal of attention has been paid to the development of the movement characteristics of the hand almost from conception to maturity. The continuing interactions between the developing intellect and the increasing complexity of hand function have not been as exhaustively studied even though the hand's use as a manipulative and explorative tool makes the importance of such interactions at least intuitively apparent. In this regard, relatively little research has been carried out to discover the development of the anticipatory and predictive aspects of prehension qualities which subtly demonstrate changes in the accuracy of the child's perception of the world. Two such qualities of prehension are readily apparent, that of size of grasp and that of force of grasp. Of these two the least studied and the focus of this thesis is the development of anticipatory grasping behaviours. The gross developmental sequence of this quality is evident: from the forceful, undifferentiated response of the newborn to the precise grip of the adult. However, surprisingly little

data is available on the actual progression and development of this skill: surprising in that a great deal of information would appear to be contained within this development, information dealing with the child's development of the object concept, conservation of weight, the use and accuracy of kinesthetic feedback, the integration of visual and kinesthetic sensory modalities as well as images of achievement in an information processing sense (Bower, 1976; Connolly, 1979). For by simply contrasting the two extremes of adult and infant behaviour in terms of anticipatory grasp pressures, it is evident that the precision of the adult is due to an accurate image of achievement formed from precise visual judgements coupled with an established kinesthetic memory, all within a conceptual framework that allows decisions based on a knowledge of the physical laws of the environment. As Bernstein (1967 p. 119) has observed,

> "Over the course of ontogenesis each encounter of a particular individual with the surrounding environment with conditions requiring the solution of a motor problem results in a development (sometimes a very valuable one) in its nervous system of increasingly reliable and accurate objective representation of the external world, both in terms of the perception and comprehension involved in meeting the situation, and in terms of projecting and controlling the realisation of the movements adequate to the situation. Each meaningful motor directive demands not an arbitrarily coded, but an objective, quantitative and qualitatively reliable representation of the surrounding environment in the brain."

This review of literature will be concerned with several critical aspects governing the development of highly skilled

prehensive behaviours. The historical origins of the study of grasping will first be examined. From this point the progression from reflexive to volitional grasping behaviours will be highlighted. Those areas of human motor functioning vital to this development, channel capacity, attentional demands and anticipation, as well as the schema or schemata will then be outlined. Finally research related to this study will be reported.

Historical Overview

During the latter part of the 19th century a tremendous fascination with human development was spawned. Research of an observational nature was the accepted procedure and by far the most popular subjects to study were the children of the researcher. While numerous studies were carried out, two in particular, one by Wilhelm Preyer (1881), the other by Bernard Perez (1885), are of particular interest.

Preyer began his description of the development of grasping, (or seizing as he referred to it), with the statement that: "Of all movements of the infant in the first half-year, no one is of greater significance for its mental development than are the seizing movements." (1881, p. 241) This concept has been echoed with varying degrees of emphasis by numerous psychologists ever since. Preyer also noted the distinction between the grasp reflex and purposive grasping observing that "the first grasping at objects, with manifest desire to have them" was first made by his son at seventeen weeks. (1881, p. 243) He described the gradual decline in predominance of the reflex in

conjunction with the rise of intentional behaviour, in particular eye-hand coordinations. He strongly associated developing intentional behaviours with previously reflexive movements, stressing the gradual, non stage-like development of grasping. Preyer then made the following attempt to explain the process by which this motor development occurred.

> "Of the many thousand nerve-fibers and muscle-fibers that must come into harmonious activity in order that such a movement may take place, the child knows nothing, but he directs already the whole neuromuscular mechanism with his will, which was generated by desire. Before he is capable of this, the sensuous stimulus that starts the seizing movements must have been repeated many hundreds of times, so that as one and the same sensation often returned, an agreeable feeling arose, a perception at first indistinct, then gradually more and more distinct, and finally an idea of the objectivity of the thing seizable could be formed. Secondly, the movement of the arm, also, which, before as well as after birth, is directed to the mouth or the face, must have been very often repeated before it came to consciousness i.e., before an idea of it could be formed, because in the beginning it was not perceived at all by the child. When, however, the desired object is represented in idea, and the movement of the arm is represented, the rapid succession of both representations favours their union, which calls into life the will. ....
>
> But in order to execute a simple voluntary movement, such as reaching after objects, similar movements must have been executed involuntarily, because only through these can muscular sensations or sensations of innervations be developed. These are, however, necessary pioneers for the voluntary motor impulses ....." (1881, pp. 253-255).

The sequence suggested by Preyer then was that repetition of the grasping reflex allowed the gradual development of voluntary grasping. This occurred as movement experiences provided

the child both with information as to how to move as well as with information about those objects within his environment. Preyer also hinted at a motivating force for this development when he observed that "a new sort of pleasurable feeling, in which an intellectual element already mingles, appears when the child begins to produce some change, especially of form, through his own activity" ...... wholly new scenes of enjoyment are entered upon with the first successful attempts at grasping objects." (1881, pp. 142-143) Here then is the suggestion of an intellectual pleasure derived from the manipulation of the environment through movement, a pleasure which could serve as a motivation for continued development.

Many of Preyer's thoughts have been echoed in the decades following his publication. In particular his notion of the gradual subsumption of the grasping reflex into voluntary movements has been oft repeated. Of importance to note as well however, is his stress on the importance of intentionality, the concept of the need for a mental representation of the movement, particularly novel movements and his strong association of cognitive pleasure derived through volitional, exploratory activities.

A second 19th century psychologist whose work is well worthy of mention within this context was Bernard Perez (1885). He too noted the gradual change from reflex to voluntary grasping but placed a greater emphasis on what he felt was a strong evolutionary association between the two states. He remarked that "...we may also reasonably regard them (reflexes) as the effect

of latent tendencies eager to manifest themselves by specialized movements: and moreover the result is facilitated by these (reflex) movements, though they may have no definite aim." (1885, p. 14) Perez also stressed the importance of intention in voluntary movement but placed a greater emphasis on the cognitive pleasure gained from intentional movement as a motivating force. He states that "I am even inclined to believe that something akin to pride - to the exultant feeling of a difficulty conquered, - has been awakened in him." (1885, p. 14) Perez also observed that maturation of both the nervous and musculoskeletal systems play a limiting role in the development of grasping, noting as well the difficulties posed by the rapid growth of the child in terms of relationships with physical environment. As indicated in the following statement he felt that the development of grasping progressed in minute stages till by the age of 15 months a remarkable level of efficiency and proficiency has been attained.

> "As for the hand, the human organ par excellence, the stages of its progress of necessity escape the analysis of an observer attempting to record them; for the movements which it executes, nearly all of them complicated, and most delicately combined, are the results of efforts and acquirements, and degrees of perfection which have gone on from hour to hour during long months. At fifteen months the hand can already touch with more or less certain discrimination and appreciation; it can sometimes measure the effort required by the nature of the difficulty, either known or inferred..." (Perez, 1885, p. 22).

Again, many of Perez's thoughts have been repeated by theorists in later years. Of particular interest to this study how-

ever is his contention that by 15 months a child is capable of making fairly precise anticipatory movements regarding the force requirements of grasping a particular object. In effect, he observed that at well under two years of age a child is capable of very high quality grasping behaviours, at least in terms of appropriate force applications.

The observations and comments of both these early developmental psychologists are worthy of attention in spite of what would appear in a more modern light to be sadly lacking research procedures. Albeit simplistic, their notations have been reiterated by many psychologists through the years and the fact alone should predicate against their light dismissal. Their quest to discover the origins and progressions of skilled prehension and its relationship with the total development of the child is still a motivating force for research today.

<u>Reflexive to Voluntary Behaviour</u>

The human infant is born possessing a large number of reflexive movements, prominent amongst which is the grasping reflex (Beintein, 1968). The grasp reflex is present at birth (in various strengths), at times allowing the child to be suspended completely by the grasped object (Bryan, 1930; Chaney & McGraw, 1932). The reflex grasp occurs when a stimulus touches the child's palm, the fingers closing firmly and without thumb opposition over the stimulating object (Dewey, 1935). The three ulnar digits close more forcefully than the index finger (Kay, 1969). The reflex grasp is persistent and demonstrates little modulation in force (Adie, 1927). Valentine (1927) found that situations which increased the arousal level of the infant tended

to increase the force of the grasp. Conversely Gesell (1928) reported that the reflex could not be elicited while the subject was asleep.

In normal development the grasp reflex slowly diminishes, the 150th day post-partum often being mentioned as an approximate temporal landmark for its disappearance (Givler, 1921). Watson (1921) however, noted its disappearance as early as the 80th day. Evidence of the grasp reflex is apparent in utero at about 121 weeks of life, (Humphrey, 1964; Hutt, 1969) and an infant born at full term after a normal gestation period will have had a large number of stimulations of that reflex (Givler, 1921).

It has long been maintained that the grasp reflex is in some way a forerunner of adult prehensive behaviours (Espenschade, 1967). As previously mentioned both Preyer and Perez had made this connection through their observations in the late 19th century. Halverson (1933), in his major studies of the development of grasping, notes the progression from reflexive to voluntary prehension but does not state any causal relationship between the two. He notes that the form of grasping exhibited by the grasp reflex differed largely from voluntary prehension in that the thumb was not involved and the index finger was not dominant. In this context the disappearance or fading of the reflex takes on large importance as it allows more mature grasping to develop. However, Halverson (1931), stated that

> "Prehension in infants progresses in a manner which indicates the presence of developmental behaviour patterns. These patterns which in early infancy appear as very crude forms of

> reaching, grasping and manipulation develop gradually and observably into highly refined and integrated systems of sequential acts."

In a later paper dealing with the acquisition of skilled grasping Halverson (1937), noted that this "process then is in large part a modification and fusion of a set of reflex and acquired activities, related and unrelated functionally, into a fluent movement, cortically controlled."

Castner (1932), in a comprehensive review of literature dealing with the development of grasping concluded that the grasping reflex "should probably be considered as a foundation for the developmental sequence which culminates in grasping on sight..."

More recently, Twitchell (1965), has made extensive observations on the relationship between reflexive and voluntary grasping. His account differs from earlier reports in that he differentiates between reflex responses, giving them a developmental sequence. For example he states that the true grasp reflex "an automatic grasping response" is not present at birth but develops by the 3rd or 4th month. While he delves considerably deeper into the progression of the grasp reflex he concludes (as well) that "each stage in the evolution of the automatic grasping reactions is associated with an increasingly complex form of volitional grasping." (1965)

Connolly (1972, pp. 341-342) maintains that

> "reflex mechanisms play some role in the development of voluntary behaviour in the human infant; prehension therefore is based on the reflex substrates which develop and change during the first months after birth ... More effective prehension involving visually

> directed reachings for the first time occurs after about four months in normal development and is preceded by the maturation of the grasp reflex."

Within this discussion however, it is important to bear in mind McDonnell's (1979) admonition that it is an over simplication to attribute mature prehensive movements simply to increased cortical control of the grasp reflex. As previously noted Halverson demonstrated the rather large differences in form between reflexive responses and even the more rudimentary voluntary grasping behaviour. The problem is clearly stated by Castle, Held and White (1964) who made the following observation:

> "The detailed analysis of the development of a sensorimotor function such as prehension inevitably raises a classic theoretical problem. <u>The human infant is born with a diversified reflex repertoire, and neuromuscular growth is rapid and complex. In addition, however, he begins immediately to interact with his postnatal environment. Thus we face the complex task of distinguishing, to the extent that is possible, between those contributions made to this development by maturation or autogenous neurological growth and those which are critically dependent upon experience or some kind of informative contact with the environment.</u>"

Piaget (1963, p. 83) stated the problem from a slightly different perspective, viewing reflexes (or reactions as he referred to them) as precursors not only of motor development but also essential to the cognitive development of the child.

> "In this respect the problem which arises in connection with reactions in the first weeks is this: How do the sensorimotor, postural, and other reactions, inherent in reactions, inherent in the hereditary equipment of the newborn child prepare him to

> adapt himself to his external environment and to acquire subsequent behaviour distinguished by the progressive use of experience?"

While Piaget did not fully answer his own question he left little doubt as to the importance of those initial movement experiences in the overall development of the child.

At this juncture it can only be stated that the grasp reflex plays an undefined but undeniably important role in the normal development of voluntary prehension. Perhaps the most salient feature of its importance is its primacy, in that the reflex allows initial, rudimentary movements of a manipulative and explorative nature. In effect it provides the initial information to the infant concerning both the movement itself and the object being manipulated. As previously stated in the theoretic rationale for this paper the uncertainty created thereby may be a powerful motivating force for development. Twitchell's (1965) observations of sequential development within the reflex itself underscores the fact that a fairly large number of different grasping experiences will be available to the infant for exposure, experiences which may form the building blocks for later voluntary grasping.

Noted earlier in this discussion was the fact that one of the most distinguishing features of the adult grasp is its appreciation of weight and its anticipation of an appropriate level of forcefulness. This is in sharp contrast to the early grasping behaviours of infants. The grasp reflex itself is generally described as being forceful and undifferentiated (Dewey, 1935) although an early study by Valentine (1927) did note that increasing the excitement of the child increased the

strength of the reflex grasp. Halverson (1932), notes that infants younger than 24 weeks "give not the slightest evidence of appreciation of form, size or weight of objects" but rather hold objects "in a persistent vice-like grip which relaxes only through sudden shock or change of activity" and that they "do not adapt the force of their grip in accordance with the weight of the object" (p. 51). Halverson (1932), contrasted this behaviour with that of infants from 60 weeks of age whose grasping he referred to as being "delicate and precise", economical in gripping pressure and as adapting pressure to the mass of the object, (p. 51). In summary Halverson states that

> "early grasping is immediate, unadjustable, forceful and tenacious. At one year grasping is deliberate, adaptable with respect to size, for, or weight of the object and only as strong or tenacious as the occasion requires" (p. 60).

Halverson concluded that "in accuracy of reaching and in precision of grasping, infants of 60 weeks rank almost on equal terms with adults in prehension of objects of regular form and of average size." (p. 61). Connolly (1972) however, in a much later and more comprehensive investigation of hand function notes "that while the 60-week-old infant may be able to grasp an object in an essentially adult manner, the development of hand function is by no means complete even by the fourth year."

Much of the increased quality in skill is attributed by Halverson to the development of higher forms of grasping behaviours such as from palmar grasping to pincer grasping, as well as to an enhanced awareness of the physical qualities of the object being manipulated. The increased anticipatory abil-

ities in terms of weight discrimination are, however, left largely unexplained. They are perhaps best explained using certain elements of human information processing theory, particularly as they pertain to motor function and control.

Channel Capacity, Attentional Demands and Anticipation

> "A capacity theory assumes that there is a general limit on man's capacity to perform mental work. It also assumes that this limited capacity can be allocated with considerable freedom among concurrent activities"

(Kahneman, 1973, p. 7). The concept of man as an information processor of limited capacity is a major component of most present day human performance models. While not a universally accepted construct (Neisser, 1976, p. 98) there is a substantial body of work in its support. (Glencross, 1978) Capacity models are generally thought to be of two different types. One model suggests that capacity is structurally limited and that "bottlenecks" are created at some point in the processing system which effectively limit information capacity. (Glencross, 1979) The single channel hypothesis of Welford (1952) and the filter mechanism concepts of Broadbent (1958) are examples of this model. The second model proposes that a general capacity exists but that input and output processes compete for that capacity. (Moray, 1967) Evidence for both models is well documented (Glencross, 1979). It is beyond the scope of this paper to document the evidence for these various models of channel capacity. The intent is simply to outline the notion that the consideration of limited capacity information processing is central to theories of human performance. The key element here

is that from this perspective, the production and control of movement will require some degree of the available channel capacity. (Whiting, 1974) The more well learned the skill involved the less attentional demands will be required and therefore the less channel capacity will be required. (Singer, 1979) Marteniuk (1979, p. 47) suggests that a novel motor task will be high in uncertainty (or potential information) and that a great deal of channel capacity or attention will be required to produce an appropriate response. Marteniuk (1979) also suggests that practice or experience at some particular skill serves to reduce uncertainty which leads to a decrease in the channel capacity required to effectively perform that response. This notion is congruent with Fitts (1964) concept of skill learning eventually achieving an autonomous or virtually attention free stage. Keogh (1977) notes that the development of movement skill is dependent upon the learner's ability to efficiently process information, thus freeing channel capacity for attention to other events. Kopp (1979) suggests such a trend in the development of grasping, commenting on the total lessening of those demands as skill improves.

The reduced channel capacity required to perform movements in a skilled manner is often attributed to some extent to the increased anticipatory abilities of the performer. (Connolly, 1977) All volitional movements assume some anticipatory aspect but skillful performance is recognized by minimal discrepancies between the actual performance of the movement and the relation to the anticipated demands of the response. (Wade, 1975) More

accurate anticipation will require less channel capacity for subsequent error recognition and correction (Whiting, 1974). Bower (1976) has speculated that the development of anticipatory ability is linked to varieties of experience, or practise. Bower (1976) also makes the critical point that accurate anticipations reflect the accuracy of the cognitive rules governing behaviour. He also notes that with increasing age behaviour appears to change less and less, while the complexity of its control processes appears to become greater and greater.

In summary, it would appear that the human information processing system is structurally limited in some way. The degree to which that capacity is used in movement responses is dependent upon the skill level of the performer. The more accurate the performer's anticipation of the task's demands the greater is the likelihood of a skilled response and its correspondingly low demands on channel capacity. Skilled performance appears to be dependent on a sufficient amount of varied movement experiences or practice at similar tasks. This experience in turn leads to the development of complex cognitive rules which govern motor behaviour in an increasingly efficient manner, resulting in the minimization of channel capacity demands. One theoretical construct dealing with the development of these cognitive rules is the schema.

The Schema

The concept of "schema" or "schemata" was first espoused by Head (1926) and later reworked by Bartlett (1932) in an attempt to explain the recognition aspects of perception, particu-

larly in relation to novel events. Definitions of schema abound and the word has become unfortunately associated with a wide number of meanings. (Neisser, 1976) The following definition, a composite of several proposed, will be employed in this thesis. The schema is a set of related cognitive rules which govern the production of movements which are similar in morphology. The schema is modifiable by experience as a result of uncertainty reduction between past and present movement responses and results. (Evans, 1967; Neisser, 1976; Pew, 1974; Schmidt, 1975). Within the context of this thesis then a schema would exist that controlled grasping behaviours, one of the associated cognitive rules being that which governed the necessary amount of force required to perform the task at hand.

Schmidt (1975, 1979) has postulated that a more robust schema will result in more efficient production of known responses as well as more accurate production of novel, but similar, responses. He suggests, as does Neisser (1976), that the strength of the schema will be a function of the number and variability of previous experiences. These experiences will allow the gradual reduction of errors between desired outcome and actual outcome of the response as the schema is strengthened. (Schmidt, 1979) Somewhat cautious support for this position has been reported from the research of Kelso and Norman (1978), Moxley (1979) and Williams (1978). Bower (1976) suggests that for the young child that such varied experience allows the child to alter those cognitive rules governing its behaviour as they create conflicts, the resolution of which demands new rules. A

similar suggestion has been made by Glencross (1979) in reference to the achievement of skilled motor behaviours. Singer (1979, p. 223) speculates that more accurate cognitive rules (or schemata) would lead to a reduced demand for attentional capacity. As strong schema allow for efficient handling of information, higher quality responses would be expected. In contrast a weak schema would inefficiently cope with information, produce a less ideal response and be forced to use available capacity to detect and correct errors as well as modify the schema itself.

In summary, schemas are modifiable cognitive rules which govern specific classes of motor behaviour. These rules are modified and strengthened through experience which allows the matching of desired and actual outcomes. Conflicts between these expectancies are detected as errors and lead to the modification and strengthening of the governing schema. As schemas become more robust they more accurately and efficiently handle information and create more appropriate responses to various task demands. This results in the use of minimal amounts of channel capacity for the skilled performer with a subsequent increase in the amount of attention available for other, non-task demands.

Control and Quality of Prehensive Forces

Precise production of force is an important aspect in the development of movement control. (Keogh, 1977) However, as Connolly (1979) has stated "To my knowledge we have almost no information on the development of the ability to control and vary forces." Kopp (1979) noted particularly the lack of re-

search governing the motor functions of older children. The investigations into the quality of prehensive skills have dealt more with the hand's relationship to tool usage than to the more elemental aspects of grasping qualities such as grasping force. The works of Connolly (1972), Rosenbloom (1971) and Saida (1979) are prime examples of this type of research. Other researchers, particularly Kopp (1974 A; 1974 B) have investigated the attentional demands associated with various skill levels of grasping among young infants. Prehensive skill was examined in terms of dexterity and not of precision of force.

Perhaps the only study that concerned itself with the precision of force application was that of Bower and Monoud (1974). While not being directly interested in this development, they employed its measurement in an attempt to guage behaviourally the acquisition of the concept of conservation of weight among young infants. They did so in part by measuring the force applied to a series of objects and analyzing the amount of force applied and the pattern of force application. Their results indicated that by 9 months of age an infant was capable of achieving a high standard of anticipatory force precision after a sequential presentation of 3 trials with some object. They also noted a gradual reduction in the peak initial force applied in the initial trial with each object as the age of the subjects increased to 21 months. Monoud and Bower do not report the type of grasp employed at various ages, the standard employed as their measure of minimum grasp force not the respective amounts of variability within each age group. Bower (1976) in a later publication suggests that by 9 months a child can and

will adjust his grip to some minimal (efficient) force. Upon subsequent trials the child will anticipate the correct amount of force necessary to that minimal force without error. Indeed he claims (1976, p. 173) that shortly after 12 months of age that the child will automatically make these corrections after only one trial with some object. Bower suggests that this behaviour reflects the cognitive rule that "the same object weighs the same every time they are picked up". Bower also suggests that by the age of 18 months that children will be able to predict the weight of unfamiliar objects and grasp them without error in force application (1976, p. 176). By this age then Bower implies that the child's grasp, in terms of force application, is as predictive, anticipatory and precise as that of an adult, in terms of grasping force.

This work by Monoud and Bower is important in that it begins to study the relatively untouched area of the development of skilled prehension. The imaginative research design employed certainly has been the blueprint for this thesis. However, the study is poorly reported, particularly in the aspects of data collection and analysis. This results in a non-replicable experiment that appears to leave as many questions unanswered or raised as it adequately contends with. Bower's suggestions as to the attainment of adult quality prehensive skills by 18 months would indicate the establishment of a highly developed psycho-motor apparatus. Yet children more than twice that age appear incapable of precisely manipulating objects in even relatively simple patterns (Saida, 1974). There would ap-

pear to be incongruencies between Bower's reported prehensive skills and the real life achievements of older children employing those same skills.

As no corrobative or disclaiming studies of Monoud and Bower's work exist their work can be neither accepted nor rejected at this juncture. The need for further study is however, evident. Equally evident is the fact that without this pioneering work the further investigation of the quality of prehensive skills would be sorely limited. This study in particular owes a great debt to their work.

Summary

From this review a number of important points may be drawn. It is apparent that while developmental scales dealing with the attainment of mature prehensive forms are well established, there appears to be a corresponding lack of understanding as to the development of skilled qualities (such as grasping forces) within those forms. As well, while the origins of grasping are assumed to lie in reflexive behaviours, little is known of the residual effect those precursive behaviours might have on the mature forms of the skill. While the physical movements themselves hold large similarities, little is known of the possible effects of the reflex organization on the skilled production of those movements. The temporal organization of force in the grasp reflex is undifferentiated and safety conscious. The temporal organization of the mature grasp is assumed to be predictive and force efficient. Finally, little data is available as to the attentional demands of a skill that has not fully de-

veloped to the mature or automated state. The attentional costs to an individual developing a motor schema to control a culturally requisite set of movements are not known. The significance to the overall development of an individual of this aspect of motor development is not understood but would intuitively at least appear to be of some import. The relationship between the demands of developing mature motor skills and the demands of cognitive development require a great deal of further study.

CHAPTER III

METHODS AND PROCEDURES

Subjects

Subjects in this study were classified by age into four groups of ten each. The age groups were referred to as 3 year olds (mean CA 2-11, range 2-7 to 3-5); 4 year olds (mean CA 4-2, range 3-9 to 4-5); 5 year olds (mean CA 5-3, range 4-11 to 5-6) and adults (mean CA 21 years, range 20-23 years).

Subjects from the 3, 4 and 5 year old groups were all participants in an Educational Gymnastics program held Saturday mornings in the Education Gymnasium at the University of Alberta. Each child was volunteered by their parent(s) following a verbal presentation and request for volunteers by the researcher. Any child who was for any reason unwilling to participate in the test session was immediately excused. This was a relatively rare occurance (2 occassions) as most children seemed to find the experience enjoyable. All children tested were caucasian males from urban middle class socio-economic backgrounds. No sensory or physical impairments were apparent.

The adult group was comprised of university students who volunteered to participate in the study. All students were enrolled in either their first or second year at the University of Alberta in the Faculty of Education. Again all subjects in this group were caucasian males from middle class backgrounds and had no apparent physical or sensory handicaps.

Males only were tested during the experiment as sex differences were not the prime focus of the study. The testing of

males only greatly simplified the acquisition of subjects.

Furthermore it was felt that if developmental differences did indeed exist in the quality of grasping that these effects might be more noticeable among males. As males are less often socialized into fine motor play activities, environmental influences on their prehensive development would be lessened, at least in the pre-school years. As well once schooling had commenced the coincidental increase in fine motor activities (scissor use, painting, puzzle solving) might result in an exaggerated effect on skill quality among male subjects. This effect, if evident, would provide some evidence as to the influence of the environment on the development of prehension, particularly in light of Schmidt's (1976) schema theory. From a very limited amount of pilot testing using young female subjects it did appear that their performance was superior to that of pre-school age males at least on the measure of grasping force.

Apparatus

Pressure measurements were recorded using a Hewlett-Packard Model 7722 polygraph utilizing a Sanborn 350-A preamplifier. The mechanical reaction of the manipulated objects was translated into an electrical trace using a model P23AA Stathan gauge or pressure transducer. The two manipulated objects were constructed from 1 in. O.D. and 3/4 in. I.D. latex tubing which was lathed down to form a wall thickness of 3/32 in. These dimensions were found through pilot testing to be a wall thickness which maximized sensitivity to pressure and yet remained strong enough to retain the circular cross-section of the tube following use, a characteristic which was essential as a failure to maintain

shape would have resulted in distorted readings. Each cylinder was weighted by filling 1/4 in. copper tubing with lead which was then inserted into the center of the cylinder. The tube was held in place, and one end of the cylinder blocked, by inserting a #2 rubber stopper to which the tube was bolted by a 3/4 in. screw. The remaining end of the tube was blocked by a #2 rubber stopper drilled through the centre to accept a length of 1/4 in. latex tubing. The result was a weighted, sealed cylinder which could be connected via the latex tube to the Stathan gauge without difficulty. The very small diameter latex connecting tube was chosen both for its ease of connection and because its own movement when the cylinder was lifted created negligible pressure changes.

Each cylinder was painted red (naphthol crimson) with non-toxic acrylic paint. The result of the lathing and painting was an outer surface on the tube that was easily seen and grasped as the outer surface was not extremely smooth. The two resulting cylinders were 5 cm and 10 cm in length and weighed 64 and 128 gms respectively. A third cylinder, used in the practice trials was 7.5 cm long and weighed 26 gms - a length and weight unrelated to the test objects. In other aspects however, such as colour and texture it was similar to the test objects.

In order to elicit the desired behaviour from the children, a test situation was designed utilizing the following equipment. Children were seated in front of a small table 42 in. x 21 in. on appropriately sized chairs. Upright from the table facing the subject was a picture of a (brightly coloured) clown's face

(11 in. x 10 in.) mounted on a white background. The clown's face was constructed in such a manner that its nose was actually a red light bulb (standard size, 10 watt, low heat) 6 1/2 in. from the table's surface which was wired to, and controlled by, a silent switch. The switch was mounted beneath the table in a location easily accessible to the researcher who was seated to the right of the child (also in a down sized chair). The surface of the table was covered in a blue velvet cloth, marked for the consistent placement of the test objects. The Stathan gauge was clamped to a retort stand behind the clown's face and out of the child's sight, while remaining within easy reach of the researcher. The wires from the transducer to the polygraph ran beneath the table and along the floor as did the power wires to the lighted nose, again out of sight of the child. The polygraph itself was situated to the left of the child in the corner of the room. The table was placed against a blank light yellow wall so that no visual distractions were available as the child faced forward.

All subjects, regardless of age, were tested in exactly the same situation using exactly the same apparatus. While this seating arrangement was somewhat uncomfortable for the adult subjects it should not have, in any way, affected their performance on the task.

<u>The Grasping Task</u>

The grasping task given to all subjects was very straightforward. Simply put, the subject was required to, in response to a stimulus provided by the lighting of the clown's nose,

lift the test object to the level of the clown's nose. When the lighted nose went off the object was to be placed down. This was repeated five (5) times in a row for each test object. The timing sequence was such that the object was picked up and held for 3 seconds and then placed back down 5 seconds after the object was replaced the second trial would begin. Following each trial the object was replaced in the "start" position by the tester. When moving from one object to the next an interval of about 20 seconds elapsed as the new test object had to be hooked up to the Stathan gauge by hand. This timing sequence was adhered to as strictly as possible but with the younger children in particular the task was impossible while retaining as relaxed an atmosphere as possible.

Instructions

Identical instructions were given to each subject. Supplementary instructions were given to individual subjects as required. The instructions and their sequence are as follows. The object used in the sessions was the practice tube.

1. "When the clown's nose lights up I want you to pick up the tube and hold it in front of the nose - like this - (followed by a visual demonstration). When the clown's nose goes off that means put the tube back down - like this - (followed by a visual demonstration)."
2. The subject was then asked, "Do you understand that?" If "no", instructions were repeated. If "yes", step 3 was then initiated.

3. A practice trial was allowed at this point. "Now you try it - remember to wait for the nose to light up." If the child was successful, step 4 was initiated; if not the error was corrected before moving on.
4. "When you pick up the tube I want you to hold it in the middle - like this." (followed by a visual demonstration).
5. A second practice trial was then asked for. "Let's try it again and remember to hold it in the middle." If the task was successfully performed, the behaviour was verbally reinforced with the phrase "That's very good." If unsuccessful the instructions were repeated. Once successful, task 6 was initiated.
6. "The last thing to remember is that I don't want you to squeeze the tube when you pick it up - Okay?" If no problems were encountered, step 7 was commenced.
7. "Now let's see if we can do all that with this tube." This phrase was spoken as the first test object was introduced. The test object was then placed on the table before the subject while the experimenter said, "Remember to wait for the clown's nose to light up". At this point testing commenced.

During the test trials correct task performance was followed by the phrase: "That's right". Incorrect performance was fol-

lowed by a reminder of what should have been done, for example - "Remember to hold it in the middle".

Between test objects, while the new tube was being connected to the Stathan gauge, the following instructions would take place:

1. "That's very good - you've finished all the times with that one, let's see if you can do the same with this one". At this point the second test object was placed in position.
2. "Remember to wait for the light, pick it up in the middle and don't squeeze it. Okay, let's try it with this one". Following this last instruction the test trials recommenced.

In response to the inevitable questions answers were given that were redirected toward the correct performance of the task. In most cases the promise of showing the child "how the clown's nose works when we've finished" was sufficient to direct attention to the successful completion of the task.

Procedures

Children were tested following their participation in a one hour educational gymnastics session. The design of these sessions was such that for the last 15 minutes the children were not active but were talking with their instructors and having a snack. While their involvement in these sessions was not part of the experimental design it was beneficial in a number of ways. First it gave the children an outlet for their energy before the test session. Secondly, it allowed them to "settle down" before testing began. As well as the test site was adjacent

to the gymnasium it was in a familiar environment and didn't require their transport to a less convenient area. Subjects were randomly tested, independent of age.

The subject and one parent were taken into the testing room. An attempt was made to familiarize the tester with the subject by asking for names, birthdates, etc. During this time the parent was shown where to stand next to the polygraph and asked if they would start the machine when asked. This procedure was found to lessen any anxiety caused by the machine's start up as the parent was associated with the machine's control. At this time the parent was asked what their child's dominant or preferred hand was. This information was compared to the hand used in the practise trials. In no case was a conflict observed. The parent was then asked to please remain silent during the test session, an instruction which for the greater part was observed. Parents spoke only to direct their child's attention either to the task or to the instructions. The child and the experimenter then seated themselves at the table holding the test apparatus and the instruction session commenced. During the test session any pertinent details, e.g. if object dropped - were noted by the experimenter. As well the type of grasp employed by the subject was noted at this time.

Following the test sessions children were shown the switch to the clown's nose and were given an opportunity to watch the polygraph's needle be deflected. Any further questions from either the subject or parent were answered, thanks were given and the session was ended. Each session lasted for approximately 10 minutes, the actual testing accounting for about 5

minutes.

Test procedures for the adult group varied slightly from those of the children's groups. While the apparatus and instructions remained identical the polygraph was started before the test session began as the adult subjects did not have a parent present. Apart from this departure the procedures remained essentially the same for all groups.

It should be noted that the test sessions took place in a temperature controlled room. Since the test objects were air filled and the pressure transducer was responding to differences in air pressure this constant temperature was important. Fluctuations in room temperature would have led to fluctuations in pressure readings. The room temperature was held constant at 68°F for each of the test sessions. The polygraph was run for 30 minutes prior to each test period to allow its temperature to stabalize as well.

Measurements

Each subject's test trial was removed from the polygraph and immediately marked as to the order of trials and the order of the objects used. Each trial was then cut from the polygraph output and placed in temporal order by trial in a booklet containing the subject's initials, birthdate and any other pertinent information. Any other information or remarks made by the experimenter (during the test period) as to type of grasp, difficulties experienced etc. was then written into the booklet opposite the appropriate trial. The results of each trial were then analyzed and the results recorded by subject for each group. The extraction of data was done blindly, that is with no

knowledge of the age of the subject or the order of presentation prior to the recording of the data.

The following protocol in measurement was followed. A baseline measure was established from the consistent pen position before grasping commenced. Grasping was judged to have commenced when the pen position rose consecutively for 4 mm (or .16 seconds). Peak pressure was judged reached when the pen position began to decline or remained constant for 4 mm (or .16 seconds). The difference in pen height from start position to peak pressure position was then computed to the nearest mm and referred to as peak pressure. This is a measurement of the initial predicted force applied by the subject. The distance the pen ran from the start position to the peak pressure position was computed to the nearest mm and referred to as the time to peak. This is simply the time taken to attain the initial predicted force. The ratio of peak pressure over the time to peak was then computed to one decimal point and referred to as slope to peak. This measurement provides an indication of the velocity of initial force application. From the point of peak pressure readings to the nearest mm were taken every 4 mm (or .16 seconds) and the pressure at each point computed as for peak pressure. This was done for 6 readings past peak pressure. These readings are referred to as peak +.2, peak +.4, peak +.6 ... to peak +1.2. Peak pressure then becomes the common point, or zero time, from which all subsequent readings can be analyzed and compared. These measurements provide information as to corrected force applications once the initial predicted force had

been applied.

This protocol was developed from extensive pilot testing and while conservative tends to minimize errors made when children fumbled or dropped the object during a trial. Some error is unavoidable in rounding to the nearest millimetre but it was not felt significant in terms of overall proportions. In very few situations was the measurement protocol the decisive factor in determining a measurement as in the vast majority of cases the measurement points were quite obvious.

Development of Test Procedures and Apparatus

It would be remiss not to make mention of the efforts involved in the development of the apparatus, procedures and instructions involved in this experiment. Over 60 children ranging in age from 6 months to 7 years, and over 50 adults were tested prior to the experiment reported here. Each test session allowed the refinement of equipment, instructions and procedures, while attempting to increase the validity of the experiment. The main functions of these pilot studies were to find the bandwidths in which the appropriate behaviour could be trapped. With the instructions this meant finding what a 3 year old could meaningfully understand without influencing his behaviour, while not making them so simplistic as to disinterest a 5 year old in the task. The main difficulty here was to limit the exploratory behaviour of the younger child - manifested by squeezing the test object - without influencing them to grasp the object in a non-normal fashion. The instruction "not to squeeze" appeared to fulfill this purpose. The lighting nose also withdrew interest

from the test object to the clown's face thus allowing a more natural grasping response.

The development of the test objects was chiefly marked by a struggle to find a wall thickness which would retain its cross-sectional rigidity while remaining sensitive enough to allow measurement of the very light grasp of the adult subject yet remaining strong enough not to collapse under the stronger grasp of the young child. Latex lathed to 3/32 in. was found to best achieve this purpose.

The calibrating of the polygraph presented yet another difficulty. With a limited amount of pen deflection available sensitivity levels had to be found which could handle the peak pressure of a child's grasp without "going over the top" while remaining sensitive enough to measure the very light grasp of the adult without "bottoming out". This remained an elusive goal and the final setting was somewhat of a compromise which virtually guaranteed that all peak pressures would be captured but which increased the chances of a ceiling effect following the peak.

The design of the test apparatus presented another problem. The interest of the young child had to be maintained over a number of repetitive trials without affecting the behaviour being measured. The task then had to be interesting enough to maintain attention without being so stimulating that it affected how the child grasped the object. The clown's nose lighting up seemed to solve this problem. The younger children were fascinated by the effect itself, the older children interested in how

it worked. In no instance, following the two practice trials, did any of the children appear overly excited or stimulated by the light. The lighting of the nose however, did remain of sufficient interest throughout the trials to remain the focus of most questions following the test session.

Test anxiety was also found to be a contributing factor to performance, increasingly so with younger children in the pilot studies. Much of this anxiety seemed to be related to the sound of test machinery and the separation from familiar environments and persons. Holding the test sessions near the gymnasium, having a parent present, having a brief familiarity session and making the test contingent on the child's willingness to participate appeared to alleviate this problem greatly. The reassurance of a parent being present, even though silent, was the largest contributing factor in this regard.

The selection of which age groups to actually test was another difficult design decision. The younger the children that could be tested the greater the likelihood of finding developmental trends. The cutoff point had to be where the child could sufficiently understand the demands of the task, while keeping the integrity of the task intact. This required a need to understand simple verbal instructions, and have an attention span long enough to complete the task itself. Over and over again in pilot testing this cutoff point appeared to be at about 2 years 6 months. This then was made the lowest age tested and was included in the group referred to as the 3 year old group. The youngest child tested was 2 years 7 months. Another child

of 2 years 6 months was tested as well but since he obviously could not understand the task instructions the test session was abandoned.

The apparatus, procedures and instructions involved in the study were the result of exhaustive pilot testing. While by no means perfect they do however reflect the best compromise possible in the given situation and under the temporal and financial restraints of the experiment.

CHAPTER IV

RESULTS AND DISCUSSION

Dependent Variables

Four dependent variables were analyzed using two and three way analyses of variance with the Tukey test employed for post hoc analysis. Following is a brief summary of those variables and their possible significance.

The first variable examined was referred to as slope. It is a measurement of force applied (measured in mm of pen displacement) over time (measured in seconds). This is a measurement of average velocity and as such provides an indication of the temporal organization of the muscular response. This variable was examined both between trials and between groups.

The second variable examined is referred to as time to peak. This is a measurement (in seconds) of the time taken from the point of secure pickup till the point of maximally applied force. This variable allows the discussion of varieties in style of grasping. That is, was the grasp force cautious (or safety conscious as in the grasp reflex (Twitchell, 1965)) or confident (as expected in a precise, predictive response (Halverson, 1931))? Again this variable was examined between trials and between groups.

The third variable analyzed is referred to as peak pressure. This is a measurement (in mm of pen deflection) of the maximum initial force applied. (The word pressure is used as the transducer actually measured changes in the internal pressure of the object. That pressure change however was the re-

sult of force applied by the subject to the object. The two terms, for the purposes of this investigation, can be used synonomously.) This variable provides an indication of the predictive quality of the motor behaviour. Peak pressure was analyzed between trials and between groups.

The fourth dependent variable is referred to as the post peak interval(s). This variable was measured in terms of the degree of pen deflection at specific time periods (.2, .4, .6, .8, 1.0, 1.2 seconds) following the attainment of peak pressure. The post peak interval(s) allow the actual quality of the grasp to be examined (relative to the efficiency of force applied) once initial predictive responses have been made. This variable was examined (with repeated measures) between trials and between groups.

These four variables will be discussed in turn and the results of their respective analyses provided. The limitations placed upon this study by the difficulties realized in the order of presentation will be resolved prior to the discussion of the remaining dependent variables.

Slope

The slope, or the ratio between pressure over time was examined using a two way ANOVA. (See table 1) No significant differences were found either between trials or between groups. No trends were readily apparent. (See figure 1)

Between Groups (slope)

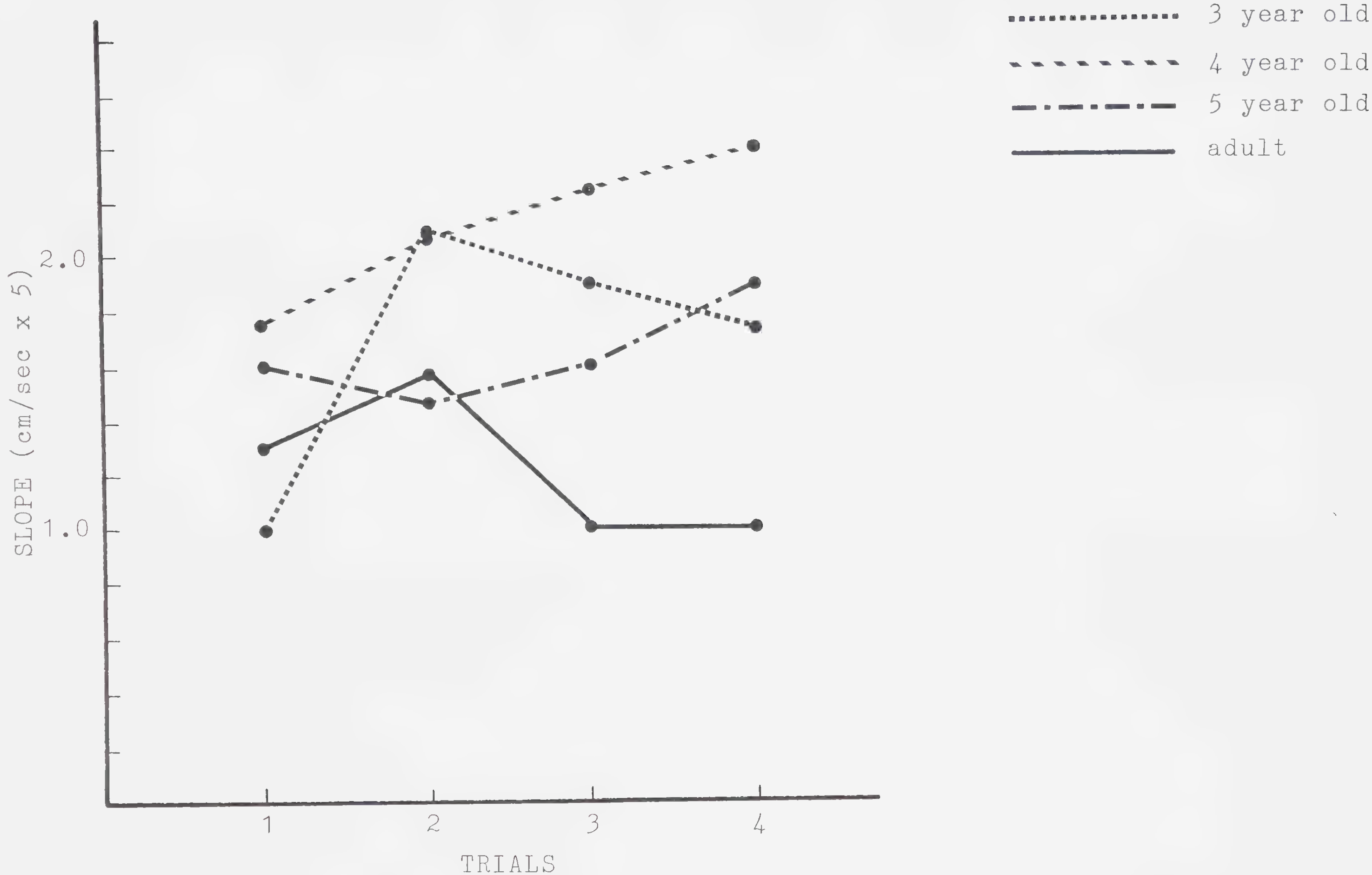
The lack of significant differences between groups is of some interest. It suggests that each age group employed similar strategies in the application of force, no matter how much

Table 1

ANOVA for Groups vs. Trials
SLOPE

Source of Variation	SS	DF	MS	F	P
Between Subjects	106.820	39			
'A' Main Effects	16.319	3	5.440	2.164	NS
Subjects Within Groups	90.502	36	2.514		
Within Subjects	92.160	120			
'B' Main Effects	3.654	3	1.218	1.644	NS
'A*B' Interaction	8.515	9	0.946	1.277	NS
'B' X Subj Within Groups	79.991	108	0.741		

fig. 1 SLOPE MEANS



force was actually applied, or how much time was taken to apply that force. The velocity of force application was relatively similar for all groups. Any differences in the amount of force actually applied then cannot be attributed to different styles of force production. It does lend itself to the suggestion that any differences in peak force application might be due to slower error corrections, slower braking responses or different levels of anticipated or acceptable grasping forces. As the time to peak pressures for all groups was very brief, around 300 msec on average, the latter explanation is likely the most probable although the influence of the prior two suggestions cannot be discounted entirely.

Time to Peak

A two way analysis of variance was employed to discover any significant differences between groups or trials on the measure time to peak. (See table 2) The analysis revealed significant differences between groups ($F = 3.629$, $df = 3$, $p < 02$) and between trials ($F = 12.12$, $df = 3$, $p = .00$). Post hoc analysis using the Tukey test revealed significant differences at the .05 level of significance between the 5 year old group and the 3 and 4 year old groups. There were no other significant group differences. Using the same post hoc testing procedure significant differences at the .05 level of confidence were found between trial 1 and all subsequent trials, 2, 3 and 4.

Between Groups (time to peak)

As noted there were significant differences between the 5 year old and 3 and 4 year old groups, the 5 year old group taking significantly longer to reach peak pressure. (See fig-

Table 2

ANOVA for Groups vs. Trials
TIME TO PEAK

Source of Variation	SS	DF	MS	F	P
Between Subjects	8.159	39			
'A' Main Effects	1.894	3	0.631	3.629	0.02
Subjects Within Groups	6.264	36	0.174		
Within Subjects	16.880	120			
'B' Main Effects	3.917	3	1.306	12.120	0.00000
'A*B' Interaction	1.327	9	0.147	1.369	NS
'B' X Subj Within Groups	11.636	108	0.108		

ure 2) This is a difficult difference to account for as it may simply reflect a more cautious approach to the task than the younger children. The older children were also more concerned with the instruction to grasp the object "in the middle". This may have led to a slightly longer contact time before pickup began, an occurance which would have led to an overestimation of their actual time to peak. It is interesting to note that this difference was not enough to create any significant differences in slope.

Between Trials (time to peak)

The time to peak for trial 1 was significantly longer than any subsequent trial. (See figures 3, 4, 5 and 6) The trend for all groups was for a shorter period of time to peak for each successive trial. This finding would appear to indicate that on the initial trial a more cautious application of force was made - that is force was applied for a longer period of time in order to ensure that the task was successfully accomplished. With each successive trial this factor became increasingly less important. The significant difference between trial 1 and trial 2 suggests that a great deal of information was gleaned from the initial trial and that the temporal organization of the grasping response was rapidly and significantly altered. This trend toward increasing efficiency continued over successive trials but at a non-significant rate. That this organizational trend of the temporal aspects of the grasp response was similar for all age groups suggests that this aspect of motor control is well established by age 3. It should be noted as well that the increased time to peak for the initial trial is possibly indica-

fig. 2 TIME TO PEAK

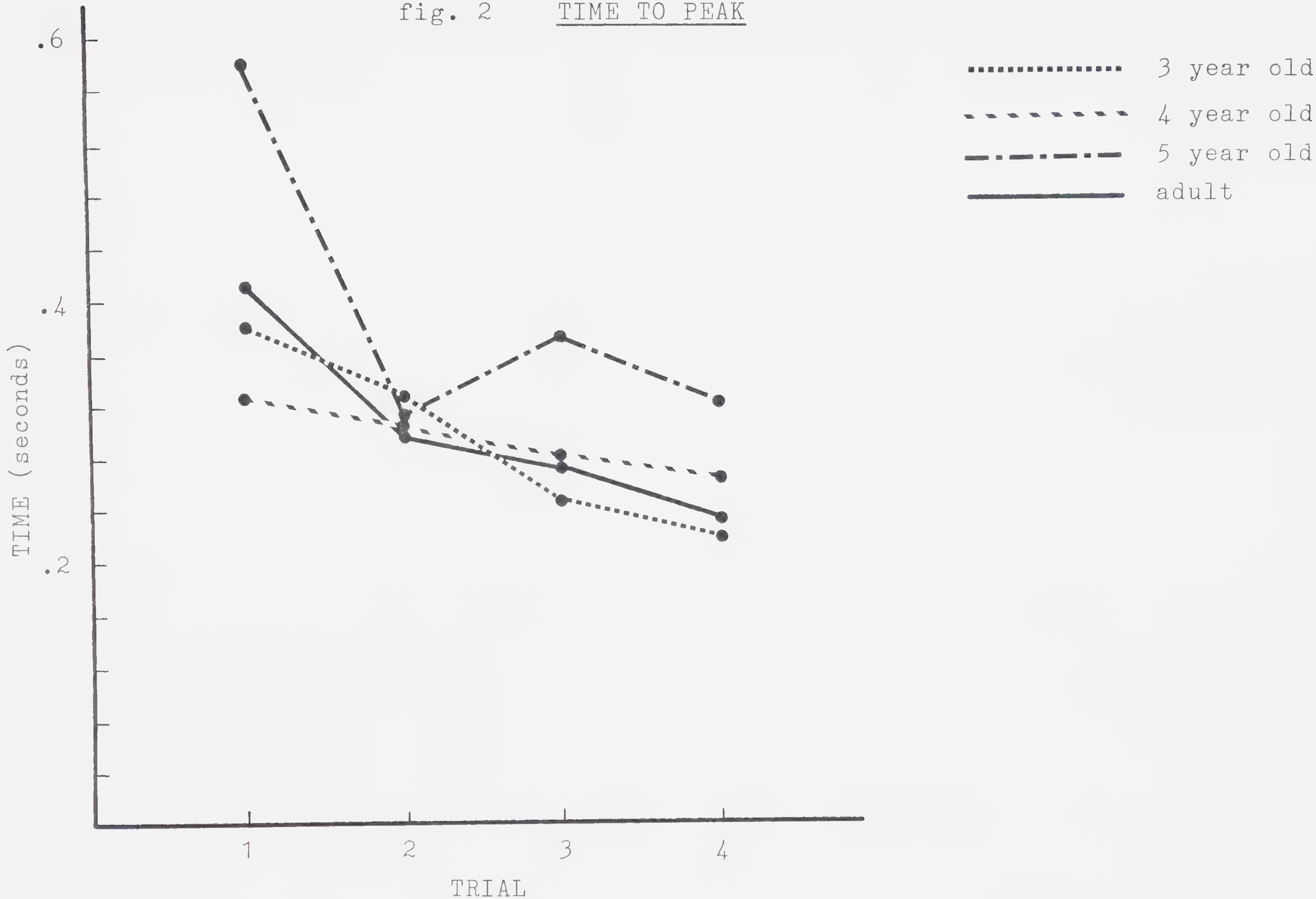


fig. 3 TIME TO PEAK, PEAK PRESSURE, POST PEAK INTERVALS - 3 YEAR OLD

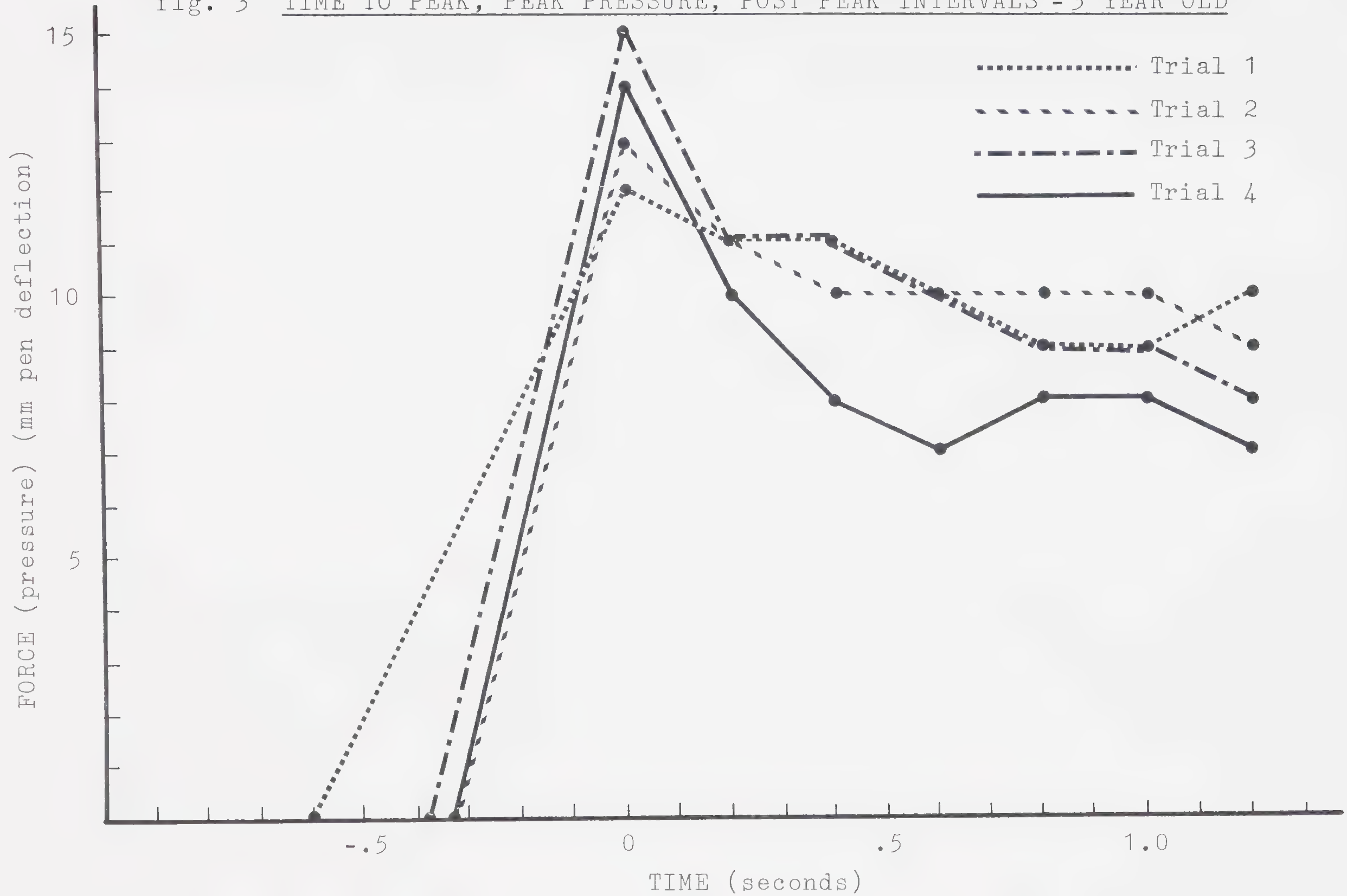


fig. 4 TIME TO PEAK, PEAK PRESSURE, POST PEAK INTERVALS - 4 YEAR OLD

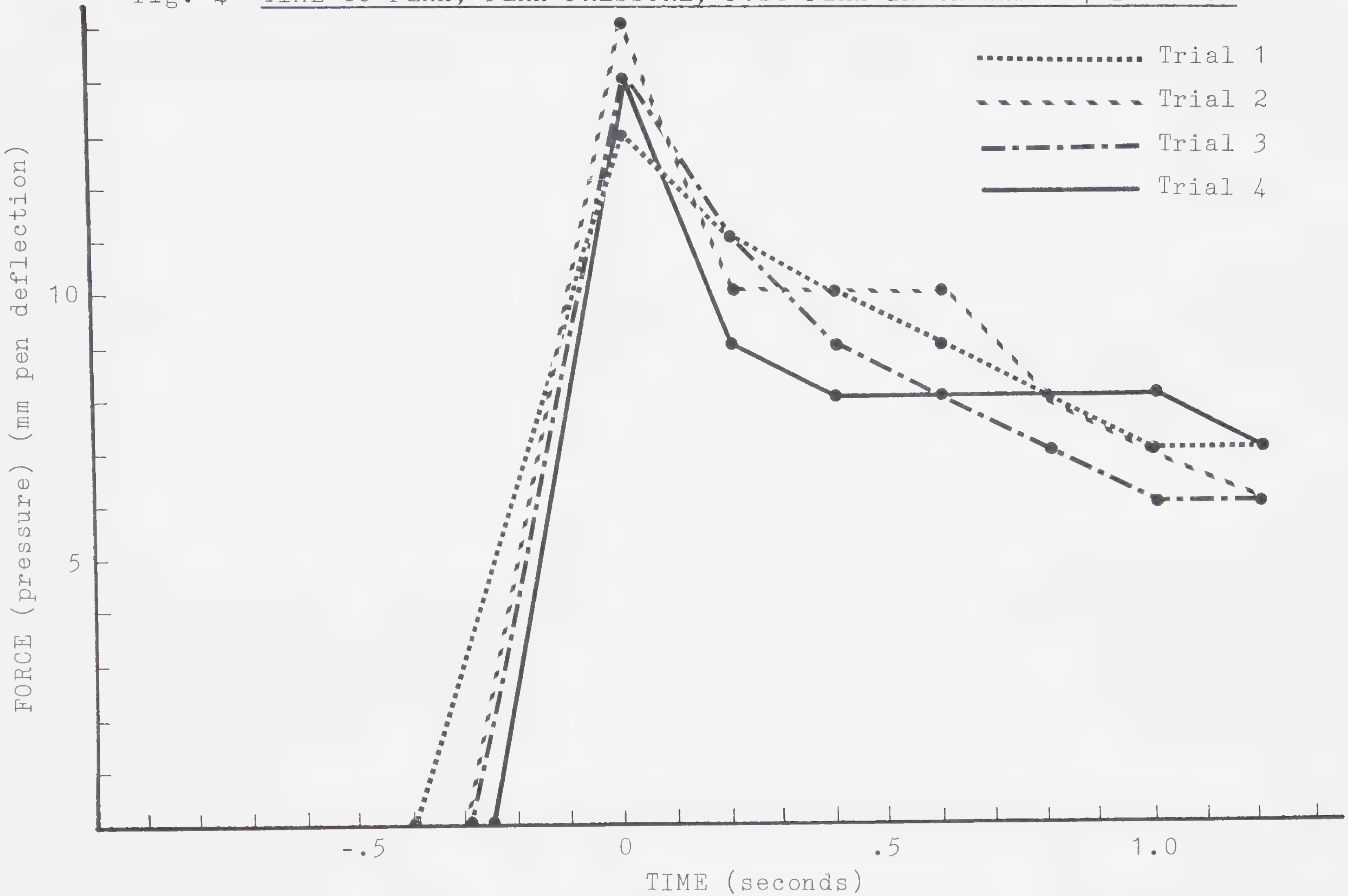


fig. 5 TIME TO PEAK, PEAK PRESSURE, POST PEAK INTERVALS - 5 YEAR OLD

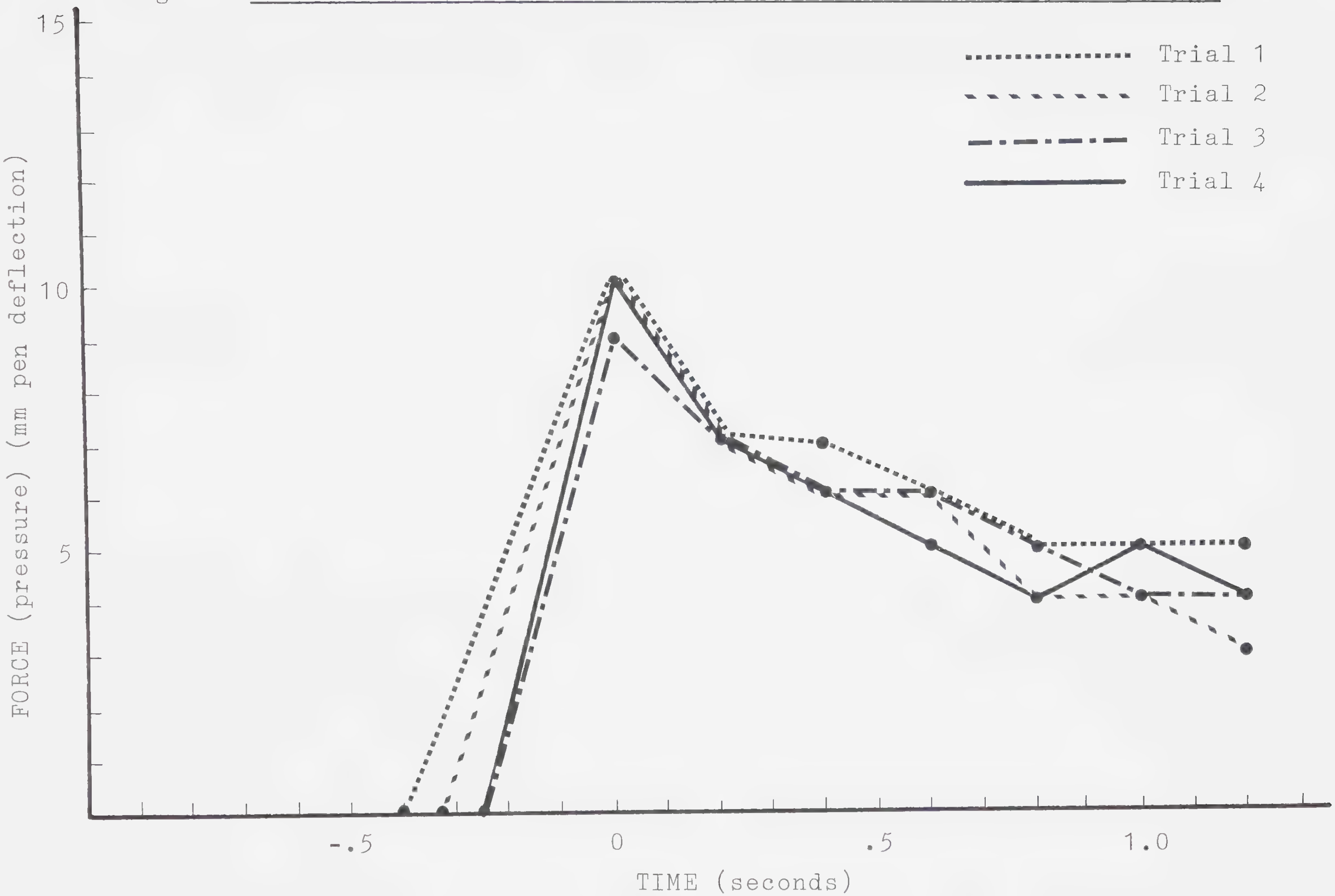
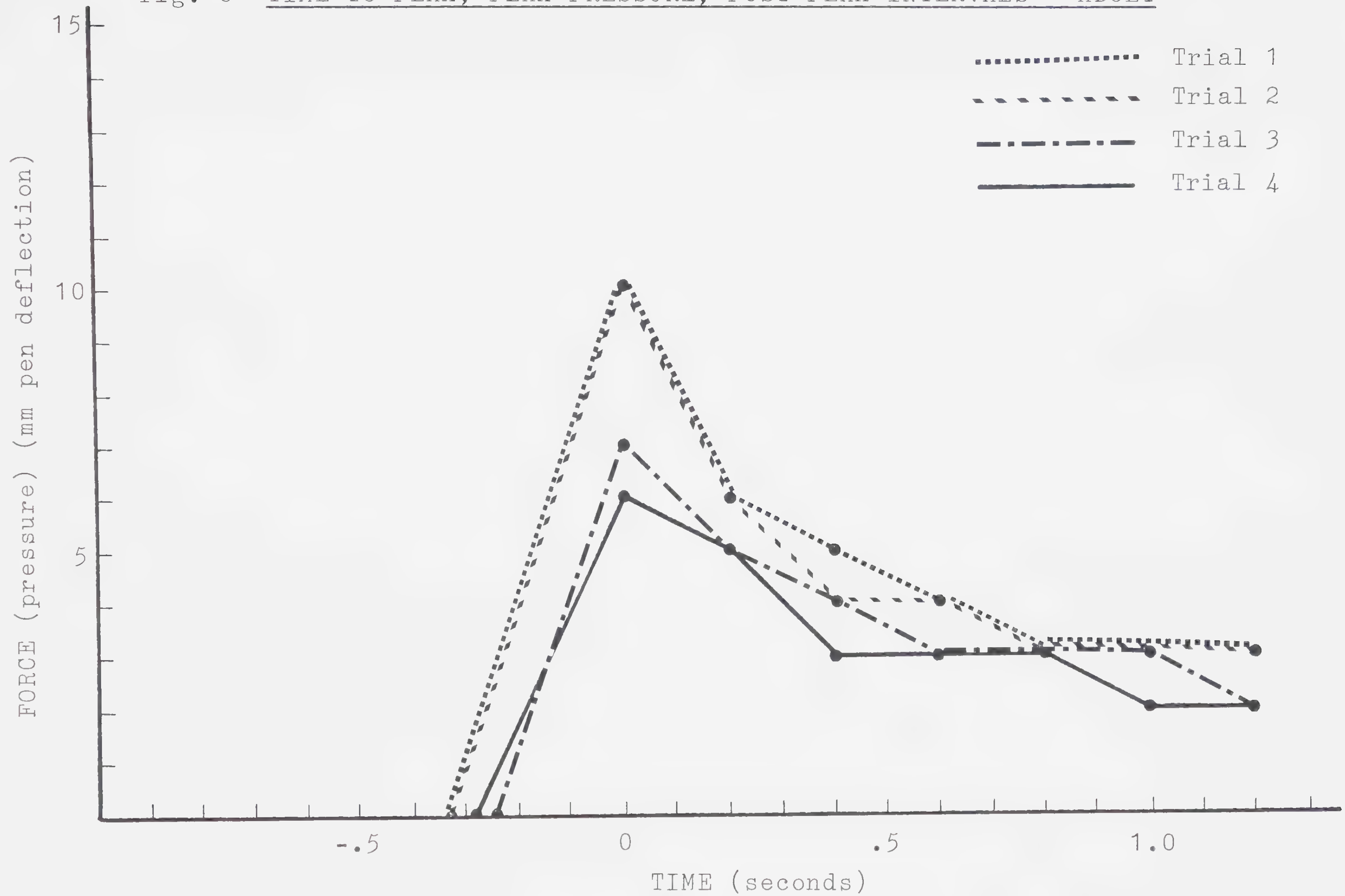


fig. 6 TIME TO PEAK, PEAK PRESSURE, POST PEAK INTERVALS - ADULT



tive of the temporal organizational style which typifies the grasp reflex. This suggestion is made as the undifferentiated response of the reflex is very much weighted in terms of force in a "better too much than too little" situation, force being applied quickly and strongly. In no instance was too little force applied, and the very conservative time to peak on the initial trial may indicate the "safety first" influence of the grasp reflex, an influence which obviously loads the response for success. This notion gains added strength since the velocity of force application (slope) remained relatively constant.

Peak Pressure

A two way analysis of variance was employed to discover the existance of any significant differences between groups on trials in terms of the peak pressure measure. (See table 3) The analysis revealed a significant difference between groups ($F = 4.733$, $df = 3$, $p < .006$). Post hoc analysis using the Tukey test revealed significant differences at the .01 level between the adult group and the 3 and 4 year old groups and between the 5 year olds and the 3 and 4 year old groups. The differences between the adults and 5 year olds is barely non-significant at the .05 level. ($F = .508$, $df = 3$, $p < .67$)

Between Trials

No significant differences were found between trials. (See figures 3, 4, 5 and 6) This is a somewhat surprising finding as it suggests that, in terms of the amount of force applied, that no significant changes in efficiency occurred. In light of the findings of time to peak it would appear that relatively the same amount of force was applied from trial to

Table 3

ANOVA for Groups vs. Trials
PEAK PRESSURE

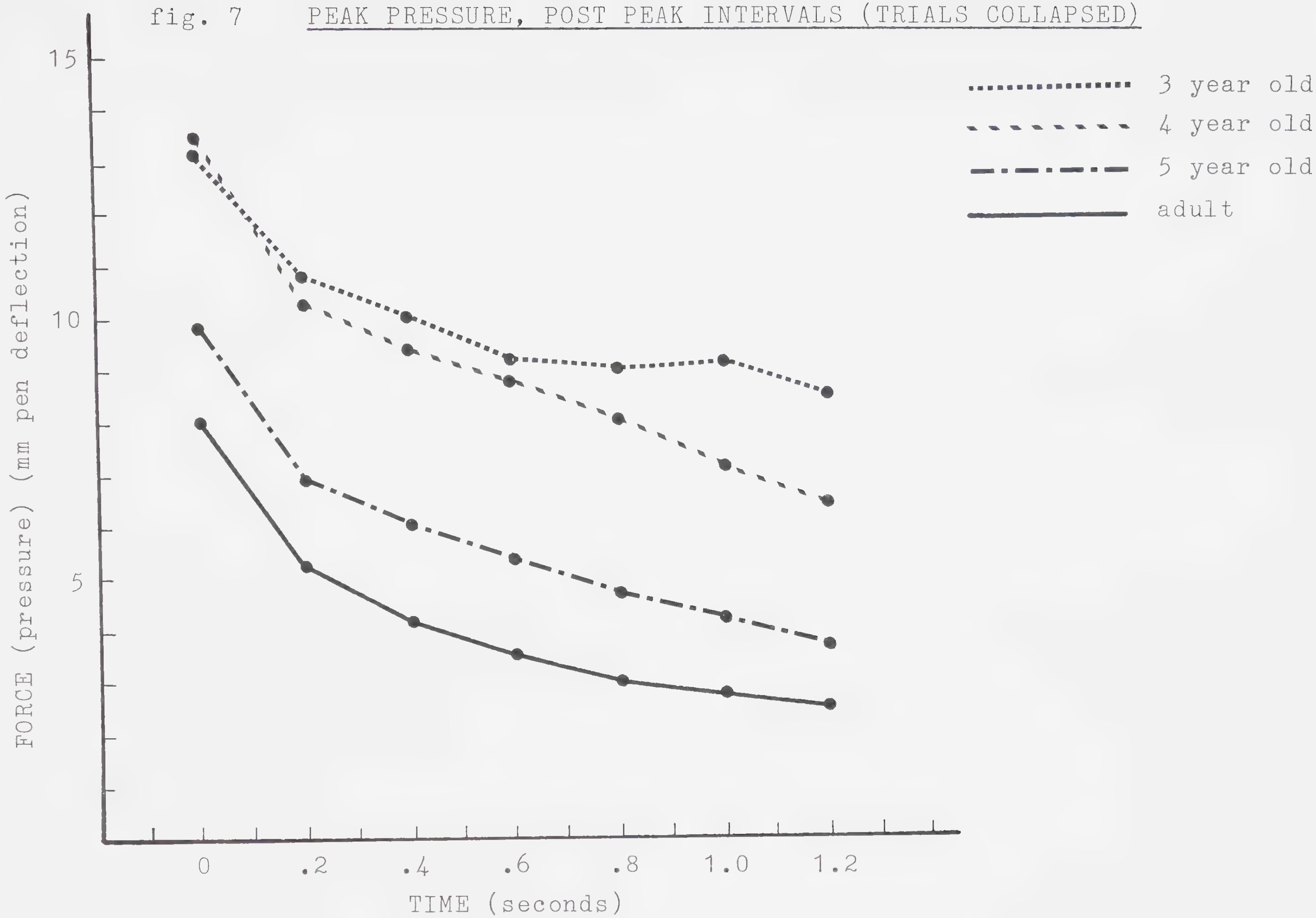
Source of Variation	SS	DF	MS	F	P
Between Subjects	2882.902	39			
'A' Main Effects	815.431	3	271.810	4.733	0.006
Subjects Within Groups	2067.457	36	57.429		
Within Subjects	2267.000	120			
'B' Main Effects	29.443	3	9.814	0.508	NS
'A*B' Interaction	150.430	9	16.714	0.865	NS
'B' X Subj Within Groups	2087.168	108	19.326		

trial, only the time taken to apply that force differed in any significant way. When looking at the cell means for each group, no trends are apparent except in the case of the adult group where the results for the 3rd and 4th trials are markedly improved over the first two trials. (See figure 6) This suggests that for the adult group some learning is occurring after two trials and that the amount of pressure being applied is becoming increasingly precise. This trend must be discussed with some caution however due to the limited number of trials reported. It cannot be stated that this trend would not appear for the other age groups after a greater number of trials. The trend does at least suggest however, that the adult group displayed more efficient error correction, perhaps due to a more highly developed schema. This in turn suggests a fast achievement of minimal capacity demands at the task. It must be emphasized however that this is only an interpretation of apparent trends, not of statistically significant differences uncovered by the analysis of variance.

Between Groups

Post hoc analysis revealed significant differences between the 3 and 4 year old groups compared to the 5 year old and adult groups. The younger children recorded significantly higher peak pressures over all trials. The trend apparent was for relatively little difference between the two younger groups with the adults generally performing better than the 5 year old groups. (See figure 7) There appears to be a large developmental jump between the ages of 4 and 5 with a smaller non-significant improvement between age 5 and adulthood. The intriguing finding

fig. 7 PEAK PRESSURE, POST PEAK INTERVALS (TRIALS COLLAPSED)



is the large increase in performance between the ages of 4 and 5. It has been postulated previously that increases in the amount and variability of grasping experiences might lead to improved motor performance subsequent to the refinement of the schema controlling those movements. (Schmidt, 1976) In light of this, the fact that the 5 year olds were all enrolled in public school kindergarten while none of the 4 year olds were, gains added significance. As many of the activities associated with kindergarten are fine motor prehensive in type (scissor cutting, crayoning, painting, etc.), it could be suggested that it is this increase in the amount and variability of grasping experiences that is the cause of the differences in performance noted in this experiment. These differences could not be attributed to different types or forms of grips employed as all subjects, regardless of age, made use of the pincer type grip. It is however an unproven assumption that there is a large increase in the amount and variability of grasping experiences for these subjects upon entering kindergarten, an assumption that precludes proof of a causal relationship. It is however a logical assumption and therefore lends some credence to the suggestion of cause.

If the initially applied peak pressure is taken as a measure of the anticipation of the required force, it is apparent that the 5 year old group is definitely superior to the younger children in the quality of their anticipation. (See figure 7) Whether this increased quality is due to a more precise knowledge of the environment, a more accurate motor control system or some combination of the two is not easily discerned. In all

likelihood it is some combination of the two factors. (Bower, 1976, p. 178) The knowledge that this initial pressure is not modified after a number of trials does suggest that the difference is due to different perceptions of what is an appropriate amount of force required to hold the object. It would appear that for each of the non-adult groups that the initial anticipation of force is sufficiently accurate but that with increasing age a more efficient understanding of what force is adequate for grasping develops. The adults' anticipations then match their expectations but the quality of their expectations is refined to allow greater grasping efficiency. It is crucial to understand that this measurement was not an indication of the potential quality of the child's grasp but rather of the normal functioning quality of the child. As such it suggests that younger children have a larger bandwidth of error in terms of grasping force. They do not expect objects to weigh more than they actually do but rather expect that they need more force to successfully manipulate the object than they actually require. This does not change over trials. The difference then is likely in the quality of the grasp itself in terms of its efficiency. The 5 year old is simply more efficient at grasping than the 4 year old, an efficiency that implies both a better knowledge of the environment and an ability to manipulate it. Increased efficiency should equate well with less error and therefore less need for error correction and therefore a reduced demand for channel capacity during normal functioning. If increased efficiency results from the accumulated corrections of errors leading to the refinement of a highly accurate schema, and if

the correction of error requires the use of channel capacity as the child strives to reduce that environmental uncertainty, then the attainment of more efficient behaviour should reflect lower channel capacity demands, even during normal functioning at the autonomous level of skill acquisition. The adult then, operating with a highly developed schema, also demonstrates the most efficient grasping and therefore has effectively minimized the capacity demands required of grasping in the normal functioning situation, thus freeing a maximal amount of capacity for other uses. This efficiency should not only be reflected in the anticipatory aspects of the grasp - time to peak and peak pressure but in the accuracy of the grasp following the initial grasp. This aspect will be analyzed by studying post peak interval.

Post Peak Interval

A three way ANOVA with repeated measures was employed to discover any differences in force application between groups and over trials at peak pressure and six subsequent (.2 second) post peak intervals. (See table 4) Significant differences were found between groups and between post peak intervals. Post hoc analysis employing the Tukey test found significant differences at the .01 level of confidence between the 3 and 4 year old groups and the 5 year old and adult groups, with neither pairing significantly different from each other. The same post hoc analysis of the post peak intervals indicated significant differences (at the .01 level of confidence) between the peak pressure and all subsequent intervals, between the .2 second interval and all subsequent intervals, between the .4 second interval and the .8, 1.0 and 1.2 second intervals and between the .6 second inter-

Table 4

ANOVA for Groups vs. Trials vs. Intervals
POST PEAK INTERVAL

Source	SS	DF	MS	F	P
Bet Subj	10857.730	39			
A	6090.7031	3	2030.2344	15.33	0.000
Subj W Group	4767.0273	26	132.41742		
Within Subj	14817.688	1080			
B	96.156250	3	32.052078	0.60	NS
AB	213.00000	9	23.666656	0.45	NS
B X Subj W G	5740.6563	108	53.154221		
C	3679.3984	6	613.23291	81.28	0.000
AC	91.566406	18	5.0870218	0.67	NS
C X Subj W G	1629.7227	216	7.5450115		
BC	79.437500	18	4.4131937	0.91	NS
ABC	161.23438	54	2.9858217	0.62	NS
BC X Subj W G	3126.5898	648	4.8249836		

val and the 1.0 and 1.2 second intervals. The peak interval (0 seconds) was the highest level recorded.

All groups displayed the same form of grasping in terms of the temporal organization of force reduction following peak pressure. (See figure 7) A very fast reduction is evident between peak pressure and the .4 second interval as evidenced by the significant differences between adjacent intervals at peak pressure and .2 seconds. The decrease continues, but more slowly between the .4 and .8 second interval as significant differences now appear at .4 second intervals. The force reduction is essentially levelled off by .8 seconds as no significant differences between subsequent intervals appear at this point although the trend is for a continued very gradual reduction in force. Figure 12 provides an indication of the differences between initial force and the level of force with which the object was eventually held.

The basic form of grasp for all groups was to apply some excess amount of force and then quickly reduce that force to a more acceptable level. The older the group, as we have seen, the lower both the initial force and the subsequent corrections. It would suggest that for grasping in normal functioning that a certain amount of error is built in the grasp itself in terms of the initial applied pressure. This system lowers the possibility of failed grasping due to too little force being applied. Again the 'safety first' influence of the grasp reflex can be seen here. As prehensive behaviour becomes more differentiated it appears to bear the imprint still of its progenitor. In pilot studies with adult subjects when asked to pick up the objects with great care this form of grasping disappeared almost com-

pletely, particularly after the first trial. In its stead a very precise anticipation was made with minimal error. This effort required a good deal of concentration and was not typical of normal prehensive behaviours. The normal form of grasping can be modified therefore but not without the intent to do so. The error creation/correction during normal functioning would appear to be at a sub-conscious level. All adult subjects were asked, following their respective test sessions whether or not they had held the objects more or less forcefully during any or between any trials. No subjects reported any noticeable differences and indeed were quite surprised to see their results indicating their consistent error corrections.

Perhaps more important to note however is the similarity in form between the age groups. This behaviour is intriguing as it is not all similar to the behaviour reported by Bower (1973) for 18 month olds. He reported essentially no error following one trial with an object. Bower does not specify what level of force was acceptable to be referred to as error free mentioning only that "a minimum pressure necessary to hold each object was determined empirically" (p. 35). If that reading had been set too high his results may have been due to a lack of sensitivity rather than the quality of grasping of the infants. Indeed, if the sensitivity of the instruments used in this experiment had been set so that the criterion pressure for measurement was that of the mean peak pressure of the 3 year old group the resultant analysis would have agreed entirely with the earlier findings of Monoud and Bower. This was not the case however and the limited results of this experiment are therefore

in strong disagreement with Bower and Monoud's findings.

Between Groups

The significant difference between the 4 and 5 year old groups confirmed that the difference noted in the ANOVA for peak pressure continued across the post peak intervals. (See figures 8, 9, 10, 11, and 12) The difference in quality of grasp between groups did not diminish in the intervals after peak forces were applied, the subsequent reductions of force being similar for all groups. Once again the argument that the apparant jump in prehensive quality between ages 4 and 5 is due to the assumed large increase in prehensive experiences can be made. As well the suggestion that children operating at a lower level of prehensive quality will require more capacity to perform some specific act is reinforced here.

Demands on capacity are not due to either the establishment of a new style or form of prehension as it is apparent that these remain quite constant over all the age groups tested. There is however a significant increase in quality of the grasp as measured in terms of applied force over the entire response. Within the perspective of this thesis this increase in quality is an indication of a more exact motor schema. That is, the set of cognitive rules governing the force production aspects of prehension has been modified through extensive and varied experience to allow the gradual refinement of a more precise and efficient response. The process of developing that motor schema requires the use of some processing capacity, the actual amount decreasing as the behaviour reaches a mature state. The percentage of capacity involved in the development of fine prehen-

fig. 8 TRIAL #1, POST PEAK INTERVALS

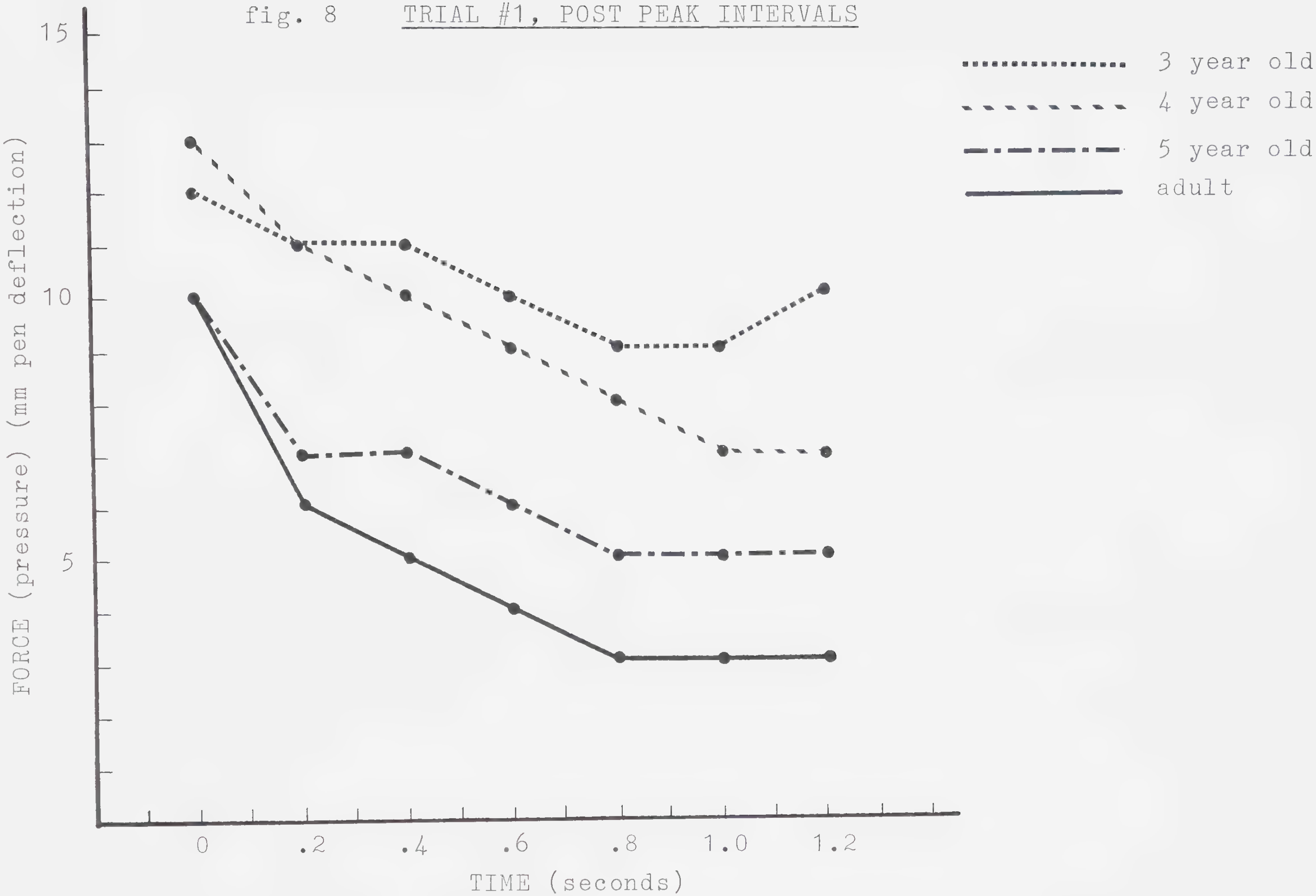


fig. 9 TRIAL #2, POST PEAK INTERVALS

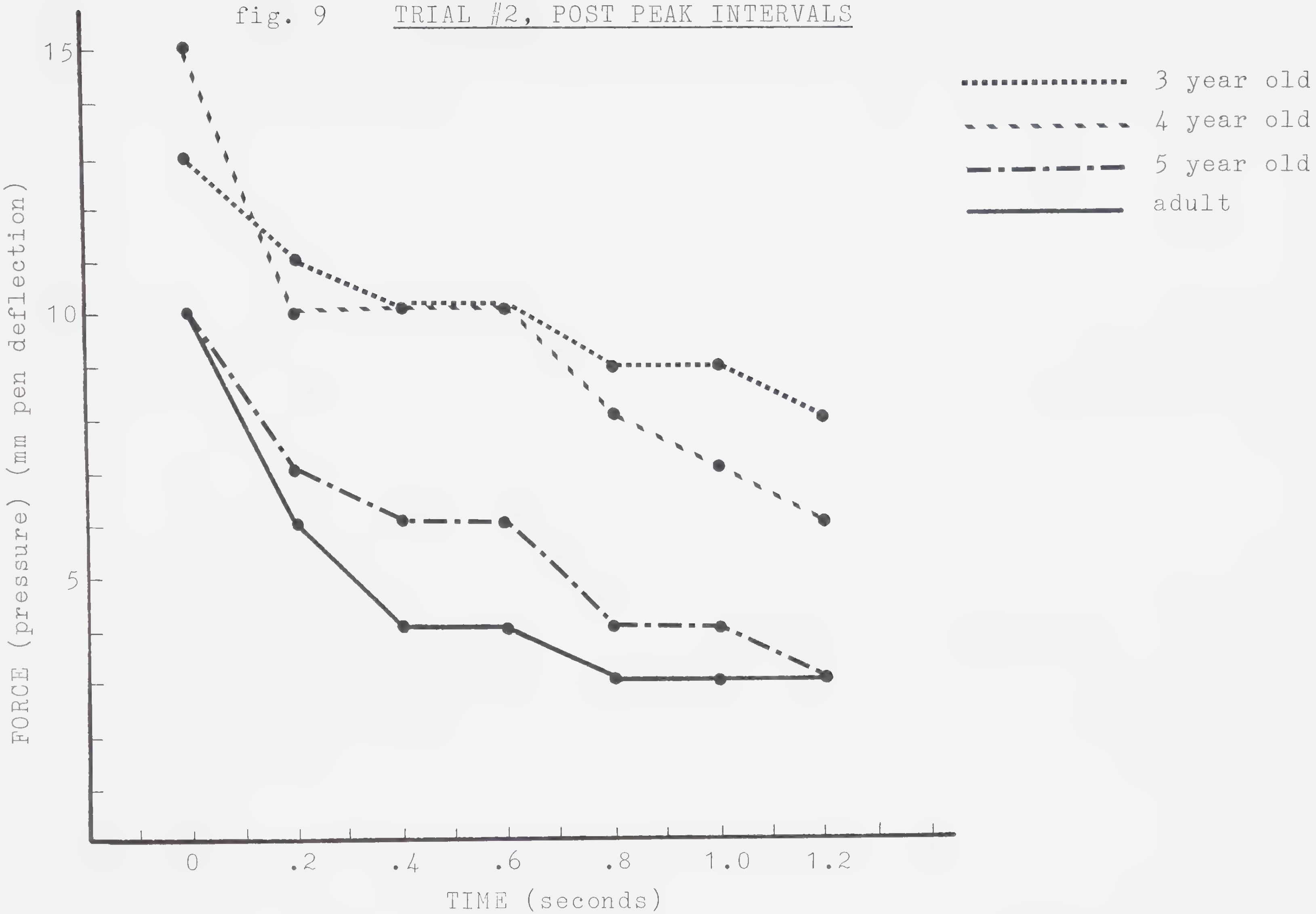


fig. 10 TRIAL #3, POST PEAK INTERVALS

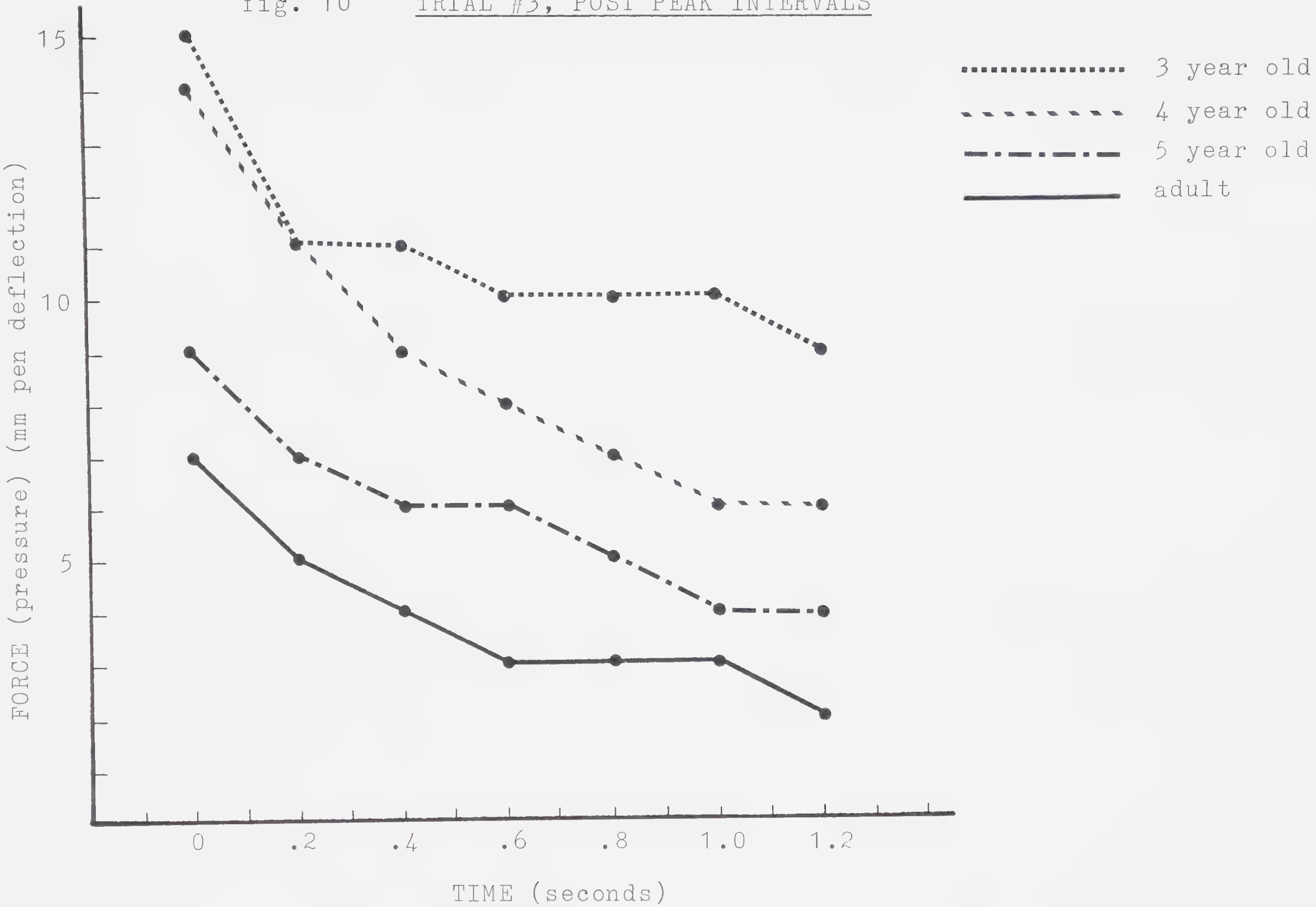


fig. 11 TRIAL #4, POST PEAK INTERVALS

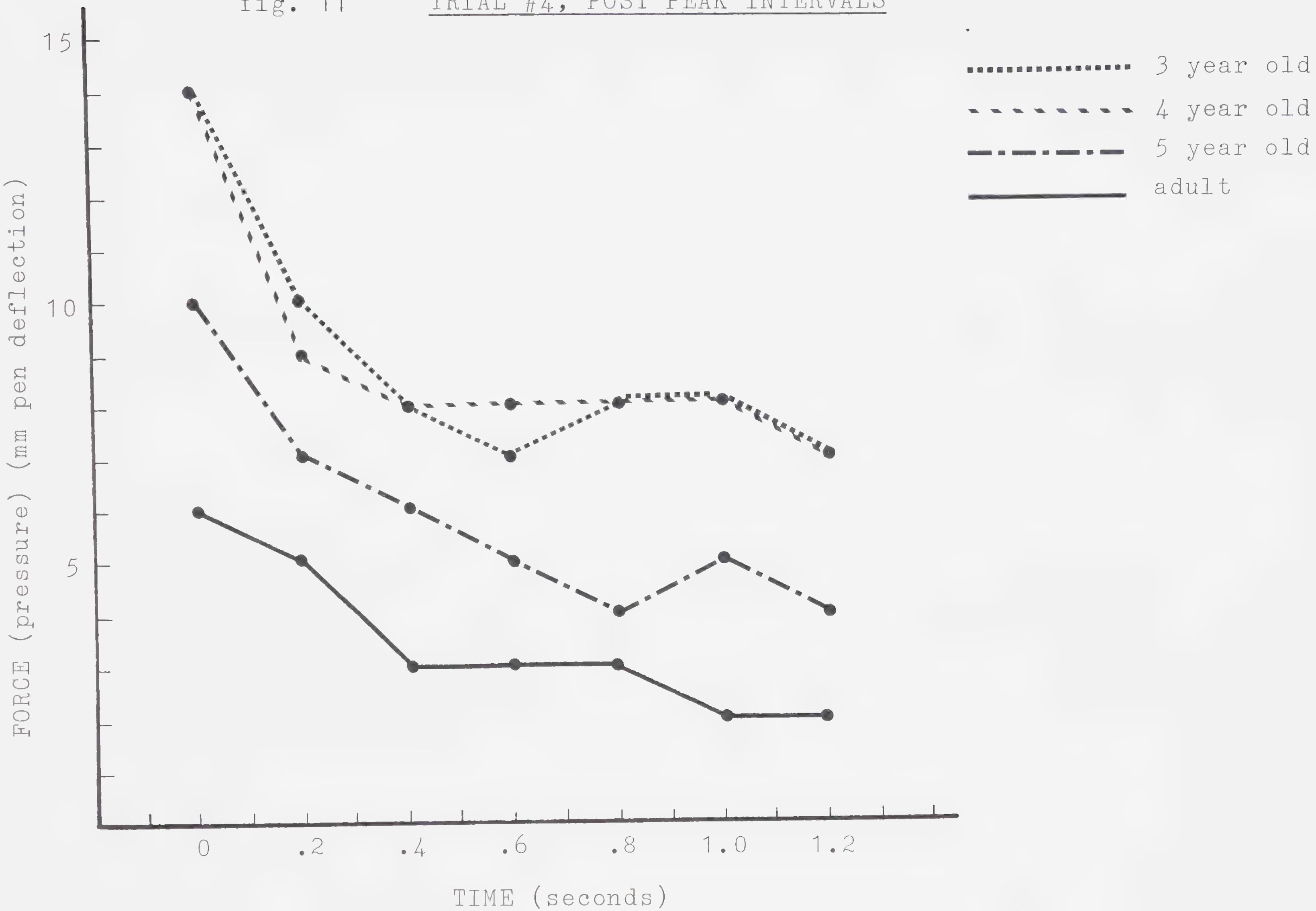
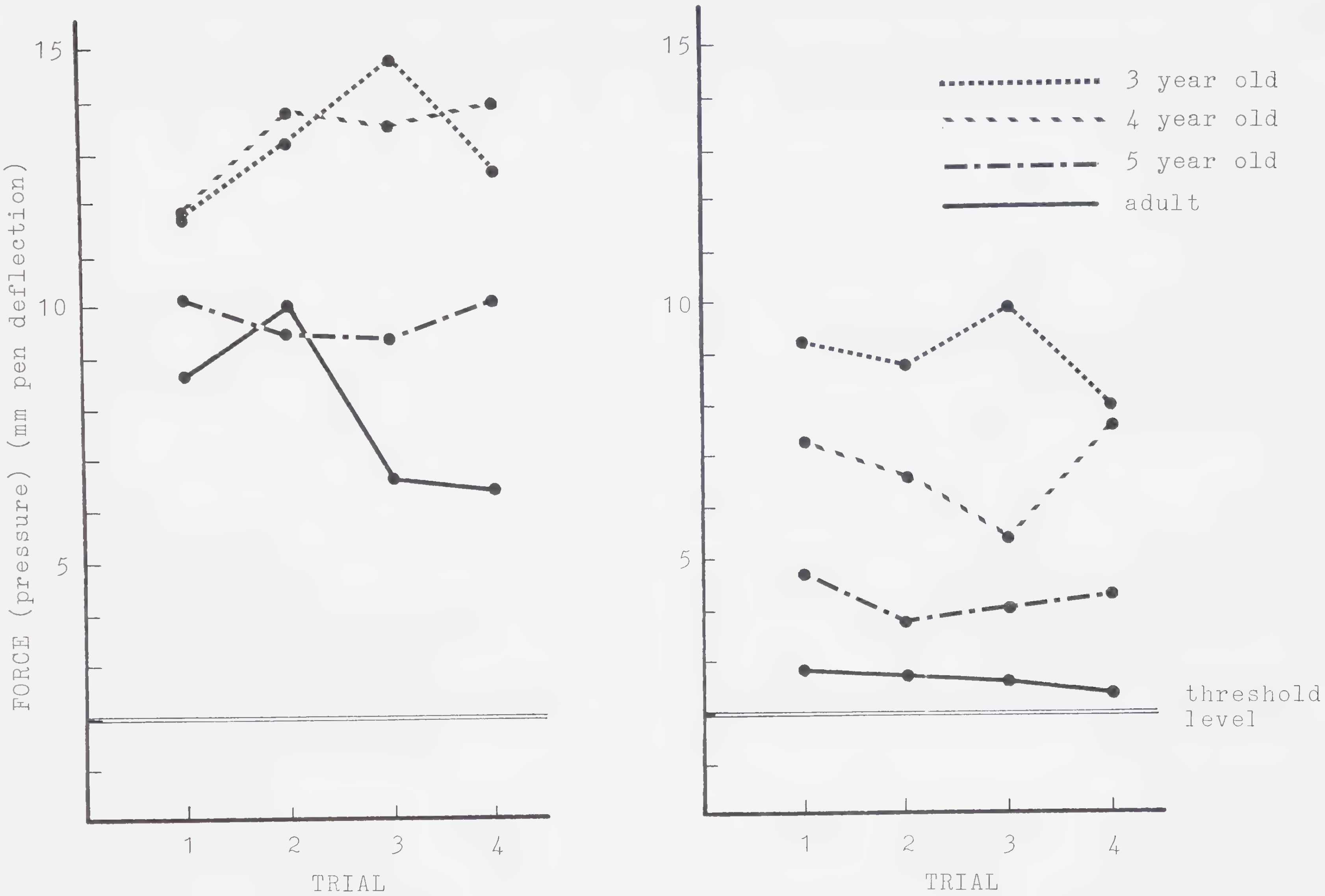


fig. 12 PEAK PRESSURE AND THE 1.0 SECOND POST PEAK INTERVAL



sive quality is not presumed to be large. For the normally functioning child this small loss of processing capacity to prehensive development is likely of no great significance to development as a whole. The loss of capacity would be of greater import however to an individual whose total processing capacity was limited.

Trials and Group Interaction

No significant differences were found between trials and apart from the adult group no trends were evident. A definite trend to reduced initial pressures following two trials was noted among the adult group but no trial by group interaction was uncovered in the ANOVA. There is a strong possibility that a type II error exists here. The power of the analysis was greatly reduced by the variability in performance demonstrated by the younger subjects. While both expected and unavoidable, the variability is extensive enough to mask any possible differences.

CHAPTER V

CONCLUSIONS

Within the constraints and limitations of this thesis the following conclusions can be drawn in reference to the previously stated hypotheses.

1. The basic form of the grasp response in terms of the temporal organization of force application was essentially the same for all age groups. Normal prehensive functioning appears to involve a deliberate error/correction sequence. The time over which the force is initially applied and the velocity (slope) of force application are not significantly different between age groups. The actual form suggests the influence of the grasp reflex as the behaviour's origin, as differentation follows a consistently overly forceful initial grasp. This is similar to the organization of the grasp reflex in that safety or success is emphasized through undifferentiated force application.
2. Older age groups demonstrated more skillful behaviour as the initial amount of force applied decreased with age. This developmental trend was significant between the ages of 4 and 5 suggesting the possibility of some environmental influence. The wide variety of prehensive experiences associated with the beginning

of schooling was submitted as a possible environmental influence. This would be congruent with Schmidt's (1975) variability of practise hypothesis.

3. No significant differences were found for any group in terms of peak pressure reductions over trials although the adult group did demonstrate a definite trend in that direction. This was not expected and may be due to the relatively small number of trials undertaken.

Overall the results indicate an increase in the quality of force application with increasing age, a developmental trend not suggested previously in the literature. The possibility of the older child having more free channel capacity available as a more robust schema is developed which allows more efficient prehension is suggested as well. The strong influence of the environment in the development of that skilled behaviour is also strongly suggested, at least intuitively, by the increase in skill level associated with the advent of formal schooling.

This investigation uncovers but a small portion of the motor development of children hitherto unexplored. The need to better understand the interactions of the development of skill quality and development of the individual as a whole remains however. The dynamic interactions of motor development with the development of the individual need to be understood before truly adequate and efficient strategies can be designed to assist that development, where assistance is needed, as well as to recognize and diagnose those individuals in need of that aid.

During the creation of equipment, the testing of subjects, and the analysis of data, a number of difficulties arose that further research could greatly alleviate. A number of the more substantial and unanswered questions and problems are presented in the following list.

1. What are the actual effects of verbal instructions on the motor behaviour of children and adults? Do children of different ages respond differently to similar instructions due to different perceptions of the meaning of the words employed?
2. Should the ratio of hand size to object size be kept consistent? Do changes in this ratio affect what is measured as normal grasping force?
3. Do differences in the alignment of shoulder, elbow and wrist between individuals of varying sizes have an effect on the force used to grasp an object. Can this difficulty be alleviated through a strictly controlled and measured placement of test objects?
4. Further testing would be greatly aided by:
   a. the creation of a research design which would allow children to be tested on a greater number of trials with a greater number of objects.
   b. the creation of a testing procedure which

would allow the testing of younger subjects with accuracy and consistancy.

c. the development of test objects which would allow precise measurement of grasping forces while not requiring specialized instructions to direct behaviour.

If further research in this area is to be undertaken, these concerns must be dealt with in order to allow a more complete understanding of development and developmental processes.

REFERENCE LIST

Adie, W. Forced grasping and groping. Brain, 1927, 30, 164-167.

Beintema, D.J. A Neurological study of newborn infants. London: Heinneman, 1968.

Bell, C. The Bridgewater treatises: IV the hand. London: Dickering, W., 1833.

Berlyne, D.E. Curiosity and Exploration. Science, 1966, 25-33.

Bernstein, N. The Co-ordination and regulation of movement. London: Pergamon, 1967.

Bower, T.G.R. Development in infancy. San Francisco: Freeman, W.H. & Co., 1974.

Bower, T.G.R. A Primer of infant development. San Francisco: Freeman, W.H. & Co., 1977.

Brainerd, C.J. Piaget's theory of intelligence. Englewood Cliff, N.J.: Prentice-Hall Inc., 1978.

Bruner, J.S. Organization of early skilled action. Child Development, 1973, 49, 1-11.

Bryan, E.S. Variations in the responses of infants during the first ten days of postnatal life. Child Development, 1932, 1, 56-77.

Castner, B.M. The development of fine prehension in infancy. Genetic Psychology Monograph, 1932, 12, 105-191.

Chaney, L.B., & McGraw, M.B. Reflexes and other motor activities in newborn infants. Bulletin Neurological Institute of New York, 1932, 2, 1-56.

Connolly, K., & Elliot, J. The evolution and ontogeny of hand function. In Ethological studies of child behaviour, Jones, N.B., Ed., Cambridge: University Press, 1972.

Connolly, K. The development of competence in motor skills. In Psychology of motor behaviour and sport - 1979, Nadeau, C.H., Halliwell, W.P., Newell, K.M., & Roberts, G.C., Eds., Champaign, Ill.: Human Kinetics Pub., 1979.

Dewey, E. Behaviour development in infants. New York: Columbia University Press, 1935.

Ellis, M.J. Play and its theories re-examined. Parks and Recreation, 1971, 51-56.

Espenschade, A.S., & Eckert, H.M. Motor development. Columbus: Charles E. Merrill Pub. Co., 1967.

Evans, S.H. A brief statement of schema theory. Psychonomic Science, 1967, 87-88.

Fitts, P.M. Perceptual-motor skill learning. In Categories of human learning, Melton, A.W., Ed., New York: Academic Press, 1964.

Flavell, J.H. Cognitive development. Englewood Cliffs, N.J.: Prentice-Hall Inc., 1977.

Freedman, D.G. Human infancy: an evolutionary perspective. Hillsdale, N.J.: Lawrence Erlbaum Assoc., 1975.

Gesell, A. The mental growth of the preschool child. New York: Macmillan, 1928.

Gesell, A., & Amatruda, C.S. Developmental diagnosis. London: Harper and Row, 1947.

Gibson, E. Principles of perceptual development and development. New York: Appleton-Century-Crofts, 1967.

Givler, R.C. The intellectual significance of the grasping reflex. The Journal of Philosophy, 1921, 18, 617-628.

Glencross, D.J., & Sharp, C.A. Competition between input and output processes. Journal of Human Movement Studies, 1978, 4, 27-35.

Haith, M.M. The forgotten message of the infant smile. Merrill Palmer Quarterly, 1973, 18, 321-322.

Halverson, H.M. An experimental study of prehension in infants by means of systematic cinema records. Genetic Psychology Monographs, 1931, 10, 107-286.

Halverson, H.M. A further study of grasping. Journal of Genetic Psychology, 1932, 7, 34-64.

Halverson, H.M. The acquisition of skill in infancy. Journal of Genetic Psychology, 1933, 43, 3-48.

Halverson, H.M. Studies of the grasping responses of early infancy. Journal of Genetic Psychology, 1937, 51, 371-499.

Hogan, J.C., & Hogan, R. Organization of early skilled action: some comments. Child Development, 1975, 46, 233-236.

Humphrey, T. Human fetal reflexes. In Growth and maturation of the brain, Purpura, D.P., & Schade, J.P., Eds., 1964.

Hunt, J.McV. The impact and limitations of the giant in developmental psychology. In Elkind, D., & Flavell, J.H., Eds., Studies in cognitive development: essays in honour of Jean Piaget. New York: Oxford University Press, 1969.

Hutt, S.J., Lenard, H.G., & Prechtl, H.F.R. Psychophysiology of the newborn. In Advances in Child Development and Behaviour, vol. 4, Lipsitt, L.P., & Reese, H.W., Eds., 1969.

Jones, F.W. The principles of anatomy as seen in the hand. Philadelphia: P. Blakitson's Son & Co., 1920.

Judson, H.F. The search for solutions. New York: Holt, Rinehart & Winston, 1980.

Kahneman, P. Attention and effort. Englewood Cliffs, N.J.: Prentice-Hall Inc., 1973.

Kay, H. Development of motor skills from birth to adolescence. In Bilodeau, E.A., Ed., Principles of skill acquisition. New York: Academic Press, 1969, 33-55.

Kagan, J. The determinants of attention in the infant. American Scientist, 1970, 58, 298-306.

Keogh, J.F. The study of movement skill development. Quest, 1977, 28, 76-88.

Kopp, C. Fine motor abilities of infants. Developmental Medicine and Child Neurology, 1974(A), 16, 629-636.

Kopp, C. Perspectives on infant motor system development. In Psychological development from infancy: Image to intention, Bornstein, M.H., & Kessen, W., Eds., New York: John Wiley & Sons, 1979.

Kopp, C., & Shoperman, J. Cognitive development in the absence of object manipulation during infancy. Developmental Psychology, 1973, 9, 431.

Kopp, C., Sigman, M., & Parmelee, A.H. Longitudinal study of sensorimotor development. Developmental Psychology, 1974(B), 10, 687-695.

Langworthy, O.R. The differentiation of behaviour patterns in the fetus and infant. Brain, 1932, 55, 265-277.

Lerner, R.M. Concepts and theories of human development. London: Addisson-Wesley Pub. Co., 1976.

Lerner, R.M. Nature, nurture and dynamic interactionism. Human development, 1978, 21, 1-20.

Lipsitt, L. Learning capacities of the human infant. In Brain and early behaviour, Robinson, R.J., Ed., London: Academic Press, 1969.

Marteniuk, R.M. Information processing in motor skills. Toronto: Holt Rhinehart & Winston, 1976.

McDonnell, P.M. Patterns of eye-hand co-ordination in the first year of life. Canadian Journal of Psychology, 1979, 33, 253-267.

McGraw, M.B. From reflex to muscular control in the assumption of an erect posture and ambulation in the human infant. Child Development, 1932, 3, 291-297.

McGraw, M.B. Suspension grasp behaviour of the human infant. American Journal of the Disabled Child, 1940, 60, 799-811.

Monoud, P., & Bower, T.G.R. Conservation of weight in infants. Cognition, 1974, 3, 27-40.

Neisser, U. Cognition and reality. San Francisco: W.H. Freeman & Co., 1976.

Newell, K.M., & Barclay, C.R. Developing knowledge about action. In Kelso, J.A.S., & Clark, J.E., Eds., The Development of movement control and co-ordination, New York: John Wiley and Sons Ltd., 1982.

Nunnally, J.C. A human tropism. In Science, psychology and communication, Brown, S.R., Ed., New York: Teacher's College Press, 1972.

Papousek, H. The development of higher nervous activity in children in the first half-year of life. In European research in cognitive development, Mussen, P.H., Ed., Society for research in child development monograph, 1965, 30.

Papousek, H. Individual variability in learned responses in human infants. In Brain and early behaviour, Robinson, R.J., Ed., London: Academic Press, 1969.

Perez, B. The first three years of childhood. New York: E.L. Kellogg and Co., 1888.

Pew, R.W. Human perceptual motor performance. In Kantowitz, B.H., Ed., Human information processing: Tutorials in performance and cognition, New York: John Wiley & Sons, 1974, 1-39.

Piaget, J. The use of reflexes. In Research readings in child psychology, Palermo, D.S., Ed., New York: Holt, Rhinehart & Winston Inc., 1963.

Twitchell, T.E. Normal motor development. Journal of the American Physical Therapy Association, 1965(B), 45, 419-423.

Valentine, C.W. Reflexes in early childhood: Their development, variability evanescence, inhibition and relation to instincts. British Journal of Medical Psychology, 1927, 7, 1-35.

Waddington, C.H. The strategy of the genes. London: Allen Urwin Ltd., 1957.

Wade, M.G. Developmental motor learning. Exercise and Sport Sciences Reviews, 1975, 4, 375-399.

Watson, J.B., & Watson, R.R. Studies in infant psychology. Scientific Monthly, 1921, 13, 493-515.

Welford, A.T. The psychological refractory period and the timing of high speed performance. British Journal of Psychology, 1952, 43, 2-19.

White, B.L., Castle, P., & Held, R. Observations on the development of visually directed reaching. Child Development, 1964, 35, 349-364.

White, B.L. The development of perception during the first six months of life read at the American Association for the Advancement of Science, Dec. 30, 1963. Reported by Twitchell, T. in Neuropsychologia, 1964, 35, 349-364.

Whiting, H.T.A. Input and perceptual processes in sports skills. Journal of Motor Behaviour, 1974, 6, 217-226.

Whiting, H.T.A. Dimensions of control in motor learning. In Stelmach, G.E., & Requin, G., Eds., Tutorials in motor behaviour, Amsterdam: North-Holland, 1980.

Zelazo, P.R., Zelazo, N.A., & Kolls, S. Walking in the newborn. Science, 1972, 176, 314-315.

Zelazo, P.R. From reflexive to instrumental control. In Developmental psychobiology: The significance of infancy, Lipsitt, L.P., Ed., New York: L. Erlbaum Assoc., 1976.

APPENDIX A

ORDER OF PRESENTATION

Objects were presented to subjects in one of two orders, either from small to large or from large to small. The intent was to discover whether experience with an object would lead to more skilled or efficient force application on subsequent objects related in size, weight and shape. This relationship was one of findings reported by Monoud & Bower (1972). Upon analysis of the raw data a major problem soon became evident. The younger children, particularly the 3 and 4 year olds had consistently failed to grasp the smaller object near its centre. This form of behaviour was consistent with notes made during testing which indicated that the smaller object was typically grasped near its end, which resulted in highly suspicious tracings and the eventual abandonment of the data dealing with the small object. No such problem arose with the large object, leaving only the possibility of examining the effect of handling the large object after grasping the small object. This was the only order of presentation effect that could be measured. The results for each order of presentation subgroup were then compared in terms of their peak pressures, time to peak pressure, and their slope to peak pressure. T tests were employed to find the significance of the difference between the means computed for the two subgroups in each of the 4 age groups. No significant differences in grasping behaviour were found for these dependent variables for any age group on any trial with one exception. For the 3 year old group, the mean peak pressure for the small to large

presentation order subgroup was found to be significantly larger on the fourth trial albeit barely ($t = 2.34$, $df = 8$, $t_{.05} = 2.306$). As no other differences were found on any other trial and as no trend was readily apparent that would indicate consistent differences between the two presentation order subgroups, this difference was treated as an anomoly and not indicative of any major effect of the order of presentation. In all further analysis the subgroups were collapsed and treated as a whole.